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STANDARDS RESEARCH

Hydrogen-Powered Forklifts Standardization

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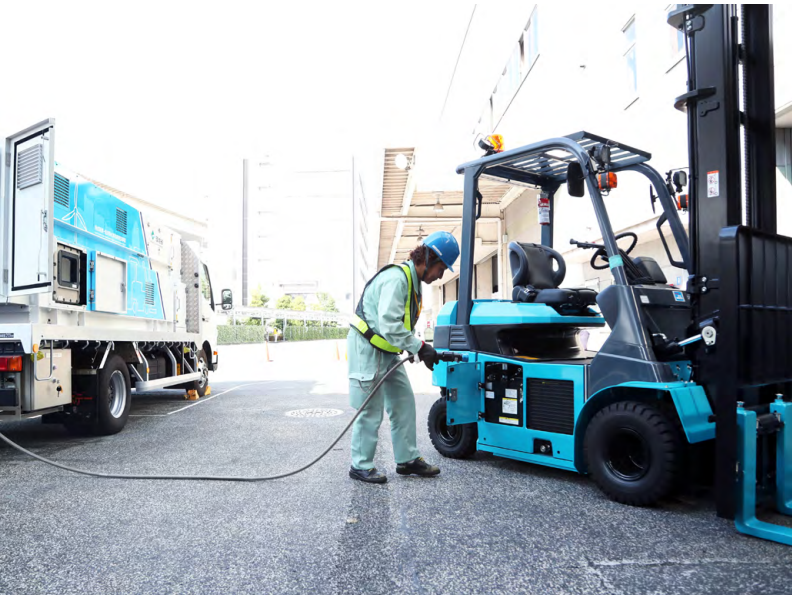
Executive Summary

Forklifts powered by hydrogen fuel cells are already in use in North America, and the market for these forklifts is expected to grow within the next decade. This research was aimed at gaining a better understanding of the needs, gaps, and opportunities for standardization of forklifts operating with a hydrogen power source. It synthesizes the findings of a literature review, an environmental scan of regulations and voluntary standards, key informant interviews, and a review of CSA B335, *Safety standard for lift trucks,* to identify where gaps exist and where there might be opportunities for improvement.

Key findings include:

- The principal hazards of hydrogen include asphyxiation in confined spaces, exposure to thermal radiation, overpressures when hydrogen is ignited or explodes, and the potential for exposure to high-velocity projectiles when a hydrogen containment vessel ruptures under high pressure.
- Research shows that the factors that contribute to forklift incidents in the workplace include work organization, workplace design, load characteristics, mechanical conditions and forklift design, age and maintenance of the forklift, and lack of or improper operator training.
- While much is known about the hazards of hydrogen and general forklift safety, relatively little is known about the specific hazards and risks introduced by the hydrogen fuel cell power system and its interaction with the hazards that are already present. Research suggests that compared to current forklift technologies, hydrogen-powered forklifts may present a higher risk of fire and explosion.
- Both the literature review and the key informant interviews identified important knowledge gaps, as well as a need for quantitative research on likely leak scenarios (including refuelling), the risk of hydrogen exposure during indoor refuelling, and whether the replacement of an electric battery with a fuel cell introduces new hazards in the workplace.
- Despite the presence of a relatively robust regulatory framework for occupational health and safety (OHS) in Canada, there are a number of gaps and inconsistencies in how forklifts are regulated in general. At present, no jurisdiction in Canada has OHS regulations that address forklifts that use hydrogen as a fuel source.
- Six voluntary standards include requirements applicable to the design, operation, and/or maintenance of fuel cell forklifts. Only one is incorporated by reference in the forklift regulations across Canada. The six standards cross-reference each other in a number of places, which could create challenges for users who would have to track down multiple standards to comply with the requirements of one standard.

The review of CSA B335 identified a number of opportunities for improvement, including the addition of reference publications, terms, and definitions, as well as amendments to the general requirements, the operator training requirements, qualifications of the lift truck trainer, maintenance and repair practices, competence of maintenance technicians, and three of the informative annexes. Given the potential consequences of a major hydrogen release, it may also be useful for the Technical Committee in charge of the Standard to develop and include an additional informative annex that discusses the properties and hazards of hydrogen.



"Forklifts that use hydrogen as a fuel source are already in use in Canada and the United States (US), and the North American market for these forklifts is expected to grow in the next decade."

1 Introduction

The rise of e-commerce, accelerated by the COVID-19 pandemic, has led to growing demand for warehouse services in Canada and elsewhere [1-3]. This, in turn, has led to an increased prevalence of forklifts, with various fuels powering them [4-7]. Legislated greenhouse gas emission targets, and the growing popularity of electric vehicles (due to their energy efficiency and environmental benefits), are expected to influence the forklift market toward alternative energy sources, such as hydrogen [8-16]. Hydrogen is a viable alternative, providing consistent power levels, fast refuelling, potentially clean and sustainable energy production, and no carbon emissions [17-27].

Forklifts that use hydrogen as a fuel source are already in use in Canada and the United States (US), and the North American market for these forklifts is expected to grow in the next decade [14, 17, 28-30]. Between 2020 and the end of 2022, the number of hydrogen fuel cell forklifts in operation in the US increased from 40,000 to over 60,000 [31-34]. Although this is currently the largest fleet of hydrogen fuel cell forklifts in the world, it still represents less than 1% of the total number of forklifts currently in operation in the US [17, 28]. The US target for hydrogen fuel cell forklifts is 300,000 by 2030 [17, 28], and it is projected that these forklifts could represent approximately 20% of forklift sales by 2030 and 60% by 2050 [17].

There are limited data on the number of forklifts in Canada that currently use hydrogen as a fuel source. A 2021 case study reported that 95 hydrogen fuel cell forklifts were in operation at a fresh food distribution centre in Alberta and that, based on fleet performance, the same technology was installed at two other distributions centres, one in Ontario and the other in Oklahoma [35]. The International Energy Agency (IEA) estimates that there were approximately 400 hydrogen fuel cell forklifts in Canada in 2022 [32].

At present, CSA B335, *Safety standard for lift trucks*, does not address hydrogen as a power source for forklifts [36]. This report addresses this gap by examining the current landscape for the use of forklifts fuelled by hydrogen, as well as the current regulations across jurisdictions that exist for these types of vehicles.

2 Purpose and Methods

2.1 Purpose

This research was aimed at gaining a better understanding of the needs, gaps, and opportunities for standardization of forklifts operating with a hydrogen power source. Its five specific objectives were to:

1. Explore the academic and grey literature on the prevalence of such forklifts by industry, the applications in which they are used, the technology being used, and the hazards and risks posed to workers.

2. Examine if and how other jurisdictions are addressing the use of these forklifts through regulations, standards, or guidelines.
3. Identify the gaps, challenges, and opportunities for standardization through targeted key informant interviews.
4. Evaluate CSA B335, *Safety standard for lift trucks,* based on the outcome of the literature review, regulatory scan, and key informant interviews.
5. Provide guidance on how CSA B335 could be amended to address and reflect the needs of forklifts that use hydrogen as a power source.

2.2 Methods

The following activities were undertaken to achieve the project's objectives: a review of the scientific and grey literature, an environmental scan of relevant regulations in Canada and select international jurisdictions, key informant interviews, and a critical examination of CSA B335 to identify clauses that involve fuel or fuel considerations and determine whether (and how) the use of hydrogen as a power source might have an impact on the language in the current Standard.

2.2.1 Review of the Scientific and Grey Literature

An iterative strategy was developed to search five bibliographic databases of scientific (i.e., peer-reviewed) and grey literature. The five databases were MEDLINE (Ovid), PubMed, Google Scholar, IEEE, and Engineering Village. Initial search terms included "forklift" in combination with terms such as "hydrogen" and "safety." The initial searches on Google Scholar yielded between 4,000 and 8,000 articles, while those on other bibliographic platforms yielded between 200 and 500 articles. The searches were rerun with the following additional terms: "occupational," "workplace," "hazards," "risk," "risk assessment," "hydrogen safety," "accident," "incident," "hydrogen refuelling," "indoor refuelling," "hydrogen refuelling station," and "fuel cell." In total, 135 articles and reports published in English between 2010 and 2024 were identified as potentially relevant. The titles and abstracts of the 135 identified articles and reports were then screened for relevance to the project. Articles were restricted to those that focused on the safety of hydrogen-powered or hydrogen fuel cell forklifts in North America, the European Union, and Australia. Based on these criteria, 68 were excluded, leaving 52 articles and 15 reports for full text review.

2.2.2 Environmental Scan of Relevant Regulations and Standards

The environmental scan identified Canadian regulations and standards that govern forklifts in the workplace. The scope of the scan was delineated by the following terms: "forklift," "lift truck," "mobile equipment," "B335," "hydrogen," and "fuel cell." Within each jurisdiction scanned, the search started with the official website of the organization with responsibility for occupational health and safety (i.e., the "regulator"). Relevant documents and webpages were downloaded or bookmarked.

All applicable statutes in Canada (as well as any related regulations, standards, and codes of practice) were examined to identify any reference to forklifts and specifically to hydrogen-powered or hydrogen fuel cell forklifts. Where a policy instrument seemed relevant to the project, the wording of the applicable section was extracted verbatim and recorded in an Excel spreadsheet. A series of tables were developed to summarize the applicable regulatory requirements, examine similarities and differences between jurisdictions, and identify any gaps in the regulatory approaches adopted and implemented. A subset of these tables is included in Appendix A, along with a table referencing the specific regulatory requirements cited in this report.

The regulatory scan focused primarily on federal, provincial, and territorial jurisdictions in Canada, but did not include offshore regulations. The European Union, the United Kingdom, Australia, and the US were also included because they have a similar occupational heath and safety (OHS) framework to Canada's or they have a more advanced hydrogen-powered or fuel cell forklift fleet than Canada. In addition to the legislation and regulations, relevant lift truck and hydrogen standards were reviewed.

2.2.3 Key Informant Interviews

To enrich our understanding of the principal safety-related issues pertaining to the use of hydrogen as a forklift power source, key informant interviews were conducted. Potential key informants were invited via email to participate, and those who agreed were contacted to arrange a virtual interview via Zoom or Teams. Prior to the interviews, key informants were provided with a high-level overview of the project's objectives and were advised that the interview would explore three questions:

1. The literature indicates that hydrogen release and subsequent ignition (immediate or delayed) are the primary hazards of forklifts that use hydrogen as a power source. Is refuelling the most likely source of these hydrogen releases? Are there other sources of concern? Is the risk of exposure to these hazards adequately addressed by existing standards? If not, is there a need for a new standard or amendments to existing standard(s)?
2. Despite a large body of literature on hydrogen overall, the literature on hydrogen-powered forklifts and hydrogen fuel cell forklifts is relatively sparse. What do you think are the primary research and/or knowledge gaps related to the safety of these forklifts?
3. What are the key gaps and challenges when it comes to regulating the safety of forklifts using hydrogen as a power source in the workplace? Might a standardization solution address these gaps and challenges? Is there a need for these forklifts to be explicitly addressed under the OHS regulatory framework?

Five individuals from across Canada and the US were interviewed. All understood the hazards of hydrogen and hydrogen-powered vehicles. Key informants included regulators, consultants, manufacturers of hydrogen-powered forklifts, and general interest representatives. Each interview lasted between 45 and 60 minutes, was transcribed using Otter transcription software, and was analyzed for common themes. Email consent was obtained from each participant to participate in the interview, and where the interview was recorded for transcription and data analysis purposes, consent was obtained before each interview began.

2.2.4 Review of CSA B335

CSA B335, *Safety standards for lift trucks,* was critically examined to identify areas where gaps existed and where there might be opportunities to address forklifts that use hydrogen as a power source. The Standard's table of contents was imported into an Excel spreadsheet and each clause was then reviewed to determine whether it involved fuel or fuel considerations and whether (and how) the use of hydrogen as a forklift power source might have an impact on the language in the current Standard. Where a potential impact was identified, relevant standards were consulted to determine whether and how it was addressed. The outcome of this review then informed guidance on how CSA B335 could be amended or expanded.

3 Hydrogen

There is a large body of literature on hydrogen, and its safety hazards are well established. Hydrogen has three important properties—wide range of flammability, low minimum ignition energy, and high burning velocity—that distinguish it from traditional fuels and make it an excellent fuel [27, 37-41]. However, these thermophysical, chemical, and combustion properties also make hydrogen extremely flammable and easy to ignite; therefore, it is an important safety hazard that can present considerable risk of injury to people and damage to property or the environment [19, 27, 37-40, 42].

3.1 Properties of Hydrogen

Hydrogen can exist in both gaseous and liquid states. At ambient temperature and pressure, hydrogen is a gas that is colourless, odourless, and tasteless [20, 37, 38, 42, 43]. The lightest element, hydrogen has a small molecular size, a low viscosity, an extremely low boiling point, a very low density, and a high buoyancy [19, 38, 41, 42]. At ambient temperature, it is 14 times lighter than air [41, 42]. To exist in the liquid state, hydrogen gas must be pressurized to its critical pressure of 13.301 bar and cooled below its critical temperature of -240.174 degrees Celsius [44, 45].

Hydrogen in air has a very low ignition energy compared to other fuel mixtures (e.g., methane in air) and, as a result, hydrogen in air can be readily ignited by static electricity or any residual electric currents in the vicinity [19, 27, 37, 38, 40, 42, 46]. Hydrogen can also be ignited by thermal (e.g., heating equipment), mechanical (e.g., friction), and other (e.g., light) sources [42]. At ambient temperature and pressure, a mixture of hydrogen in air is flammable at concentrations between 4% and 75% by volume, and is explosive at concentrations between 18% and 59% by volume [20, 37, 38, 42, 43, 46, 47]. In oxygen alone, hydrogen is flammable at concentrations between 4% and 95% by volume [41]. Pure hydrogen flames are not visible to the naked eye [38]. The colour of a pure hydrogen flame is pale blue, but it appears yellow if impurities are present [39, 41, 43]. Because hydrogen flames do not include smoke and have both low radiant heat and low flame emissivity, they are difficult to see and feel [41]. Hydrogen has a high burning velocity of approximately 300 centimetres per second [41, 42].

3.2 Hazards of Hydrogen

Due to its small molecular size and low viscosity, hydrogen can diffuse through porous materials, as well as leak or escape through small holes, gaps, cracks, or piping connections [37, 41, 42]. On a volumetric basis, hydrogen is released at a much greater rate than either natural gas or propane [42]. In many metals, exposure to hydrogen causes loss of ductility and degradation of their mechanical properties [37-39, 41, 42, 48]. This phenomenon, which is referred to as hydrogen embrittlement, occurs when hydrogen diffuses into and attacks the metal [19, 26, 27, 37-39, 42, 48]. Hydrogen embrittlement can result in equipment or mechanical failure if cracks and fractures form and begin to self-propagate due to a continuing accumulation of hydrogen and increasing pressure. This can lead to catastrophic failure and the release of hydrogen into the ambient environment [42, 48-50].

In open spaces, hydrogen rises and diffuses quickly; however, in enclosed and confined spaces, it can accumulate and displace oxygen, thereby increasing the potential for asphyxiation and explosion should an ignition source be present [38, 41-43, 46, 51]. Hydrogen ignition results in jet or flash fires [37, 38, 41, 42] and, in confined or enclosed spaces, ignition results in an explosion, which can either be a deflagration or a detonation event [38, 41, 42, 46, 47]. Generally, a deflagration is a confined event, and the flame spreads at subsonic speed; whereas a detonation is not a confined event, and the flame spreads at supersonic speed [42, 52]. Therefore, the major hazards of hydrogen are (a) asphyxiation in confined spaces, (b) exposure to thermal radiation and overpressures if hydrogen is ignited or explodes, and (c) the potential for exposure to high-velocity projectiles if a hydrogen containment vessel ruptures under high pressure [42].

4 Forklifts

Forklift is a term commonly used to refer to a powered industrial truck that lifts, moves, raises, lowers, and stacks objects in materials-handling operations [53, 54]. Other terms used include industrial truck, lift truck, and fork truck [54]. CSA B335 defines a forklift as “a lift truck equipped with load carriage and forks for transporting and tiering loads” [36]. The term “forklift” is predominantly used in this report.

4.1 Classes of Forklifts

Forklifts are categorized into seven classes: electric motor rider trucks (Class I), electric motor narrow aisle trucks (Class II), electric motor hand trucks or hand/rider trucks (Class III), internal combustion engine trucks (solid/cushion tires; Class IV), internal combustion engine trucks (pneumatic tires; Class V), electric and internal combustion engine tractors (Class VI), and rough terrain forklift trucks (Class VII) [55-57]. Factors that determine how a forklift is classified include power source, tire type, load capacity, lift height, size, maneuverability, specialized design features (e.g., side-shifting mast or high-reach lifting attachment), application, and intended operational environment (i.e., indoor vs. outdoor vs. rough terrain) [55, 56].

4.2 Forklift Power Sources

Forklifts are powered by internal combustion engines (ICEs) or by electricity [54, 58]. At present, forklifts powered by ICE principally operate on different types of fuel such as gasoline, diesel, liquid petroleum gas (i.e., propane), and compressed natural gas [54, 58, 59].



"Although hydrogen is a high-energy fuel, it has not been considered a viable fuel source for internal combustion engines until relatively recently."

Electric forklifts, which operate on large rechargeable batteries, have traditionally used lead acid or lithium-ion batteries [54, 58-60]. In recent years, hydrogen fuel cells and hybrid systems (i.e., a combination of traditional batteries and fuel cells) have emerged as alternative power sources for electric-powered forklifts [54, 58].

Although hydrogen is a high-energy fuel, it has not been considered a viable fuel source for internal combustion engines until relatively recently [24, 25, 27, 39, 40, 61, 62]. Two reasons for this are hydrogen's very low density and its small molecular size [40, 63]. The impact of its very low density is that very large storage tanks are required unless the hydrogen is significantly compressed or converted to a liquid. The impact of its small molecular size is that the molecules will diffuse out of the storage tank unless it is constructed with special materials [40, 63]. Hydrogen ICEs are under development by engine makers and original equipment manufacturers; however, at the time of writing, the significant investments being made in research, development, and demonstration of the technology appear to be targeting heavy on-road commercial vehicles, not forklifts [25, 64, 65].

4.2.1 Forklifts Powered by Hydrogen

At present, forklifts powered by hydrogen use fuel cell technology, not hydrogen ICEs. These forklifts use electricity to provide propulsion or auxiliary power. However, rather than drawing electricity from an electric battery, they generate electricity in a fuel cell that is powered by hydrogen. A fuel cell or a fuel cell stack is a device that creates electricity using a chemical reaction between hydrogen (or a hydrogen-rich fuel) and oxygen [66-68]. The only products of the reaction are electricity, water, and heat [66-68].

Fuel cell forklifts are typically powered by hybrid powertrain systems that have both a fuel cell stack (which is the power source) and a buffer battery or supercapacitor (which stores energy from the fuel cell and from regenerative braking for use during peak demand) [69-72]. A fuel cell stack consists of individual fuel cells combined in series to increase the amount of electricity generated. There are six principal fuel cell technologies: polymer electrolyte membrane (also known as proton exchange membrane) fuel cells, direct methanol fuel cells, alkaline fuel cells, phosphoric acid fuel cells, molten carbonate fuel cells, and solid oxide fuel cells [49, 67, 68, 73-75]. At present, polymer electrolyte membrane fuel cells (PEMFC), which are primarily used in transportation and vehicle applications, are reported to be the most suitable type of fuel cell for powering industrial trucks and forklifts [76, 77]. Because liquid methanol offers certain advantages over hydrogen (i.e., less expensive, more plentiful, easier to deliver), direct methanol fuel cells (DMFC) may become more prevalent in materials-handling applications in the future than PEMFCs [78].

Advantages of hydrogen-powered forklifts include faster refuelling time (i.e., three to five minutes) than traditional rechargeable batteries, consistent and constant power

(i.e., the fuel cell maintains a constant voltage and doesn't deplete so long as there is hydrogen in the tank), minimized downtime and increased productivity (i.e., the forklift doesn't need to be taken offline for hours of battery recharging), increased space for production activities (i.e., fuel cell refuelling stations and storage tanks take up less space than battery rooms), and decreased complexity of tasks associated with battery changeout (i.e., the need to lift heavy batteries filled with sulphuric acid overhead) [69, 71, 78].

Hydrogen-powered forklifts are either purpose-built or are repurposed electric forklifts that have been converted to fuel cell system–powered forklifts. Factors that need to be taken into account when replacing an existing power train with a fuel cell power system include size and weight of the fuel cell and enclosure; stability and centre of gravity; regenerative braking; user interface; refuelling; reliability, maintenance, and repairability [70, 72]. Size and weight are an important consideration because electric forklifts are designed to use the battery as a counterweight to the lifting loads [70, 72, 78]. Therefore, fuel cell systems installed in repurposed electric forklifts must be of an equivalent size and weight to a conventional battery [72]. No data were found on the proportion of purpose-built vs. converted hydrogen fuel cell forklifts in the workplace.

4.3 Hazards and Risks of Hydrogen-Powered Forklifts

There is a large body of literature on general forklift safety and the factors that contribute to forklift incidents in the workplace. These include work organization, workplace design, load characteristics, mechanical conditions and forklift design, age and maintenance of the forklift, and lack of or improper operator training [79]. Hydrogen-powered forklifts are also subject to these safety issues; however, there is very limited literature on the specific hazards and risks introduced by the hydrogen fuel cell power system and its interaction with the hazards that are already present. Of the articles reviewed for this project, only nine addressed the hazards and potential risks of hydrogen-powered forklifts [20, 80-87]. These studies investigated the potential for release and ignition of hydrogen from fuel cell–powered forklifts in enclosed or partially enclosed spaces, assessed the risks associated with various leak scenarios for a garage in which light-duty hydrogen vehicles were repaired, and assessed and quantified the risks that hydrogen forklifts and repurposed electric trucks pose. All were numerical simulations or probabilistic modelling studies; some were intended to inform the development of evidence-based standards, safety guidelines, or engineering tools.

In one study published in November 2012, researchers simulated the release of 0.8 kg of hydrogen from a fuel cell–powered forklift into a 1000 cubic metre enclosure, using a subscale model, and collected experimental data on dispersion behaviour and combustion phenomena [80]. The parameters for the hydrogen leak scenario were based on industry specifications, indoor refuelling guidelines in the 2011 edition of National Fire Protection Association (NFPA) 2, *Hydrogen Technologies Code,* and a failure mode and effects analysis (FMEA) that was developed in consultation with the original equipment manufacturer [80]. FMEA is a method designed to identify and understand the ways in which a system's components and elements can fail and the effects of failures on the system or process. Dispersion data showed that within three seconds of the release, hydrogen was measured at the ceiling of the enclosure, and within four seconds, no hydrogen was detectable at the release point. Combustion data showed that when ignited near the forklift, the hydrogen plume burned quickly and caused a moderate overpressure (i.e., a transient higher-than-normal atmospheric pressure caused by an explosion's shockwave), followed by a secondary ignition of hydrogen at the ceiling less than a second later and another overpressure of 24.6 kilopascals.

In another article published in 2020, researchers reported on the findings of a predictive modelling study conducted in the European Union as part of the Improving Hydrogen Safety for Energy Applications (HySea) through pre-normative research on vented deflagrations project [86]. The HySea project entailed (a) full-scale controlled experiments in which compressed hydrogen was released, dispersed, and detonated in 20-foot ISO containers and (b) theoretical modelling and simulations of vented hydrogen deflagration events. This article compared the findings

from controlled experiments in the ISO containers and a 45.4 cubic metre scaled warehouse facility with predictions from a computational fluid dynamics tool. The two different spatial scales were selected because they applied to accident scenarios in warehouses with hydrogen-powered forklifts. Based on their analyses, the authors found that the simulations performed by the validated model were reasonably accurate for risk assessment purposes and concluded that "for large warehouses with a limited inventory of hydrogen (e.g. the on-board capacity of a hydrogen-power forklift truck), the shock wave from a localized explosion will most likely be the primary concern with respect to the structural response of building elements. The local fuel concentration and the level and nature of the congestion within the volume occupied by the flammable cloud will probably be the controlling factors with respect to flame acceleration, and eventually the strength of the shock wave" [86]. They further noted that the simulation results "show that explosion venting does not represent an effective means of mitigating the effect of hydrogen explosions in large warehouses where the maximum size of a flammable cloud is determined by the inventory of hydrogen in the forklift trucks" [86]. They recommended that further research be undertaken to explore the development of a similar methodology to credibly assess worst-case consequences in realistic congested enclosures (i.e., pallet racks filled with empty pallets) [86].

In a simulation and modelling study published in March 2021, researchers conducted a hazard and operability (HAZOP) risk analysis to identify the types of leak scenarios that might be significant in a garage in which hydrogen fuel cell vehicles were repaired, and to assign a level of risk to each scenario [81]. A HAZOP study is a risk assessment approach that systematically reviews the safety of designs or examines existing processes and operations. The findings from the HAZOP study were then analyzed to examine the impact that four ventilation scenarios could have in a situation where the venting system was prematurely disconnected and hydrogen was released into a representative 12-bay maintenance facility. The leak scenario, which was developed in consultation with hydrogen fuel cell vehicle manufacturers, involved an underside leak through a mid-pressure port in the tank of a light-duty fuel cell vehicle tank; the tank was assumed to be holding 2.5 kg of compressed gaseous hydrogen and the leak diameter was assumed to be 0.86 mm. Computational modelling found that it would take approximately 3.75 hours for a full tank to completely empty because of a slow leak with these specifications. Based on their analyses, the authors found that the flammable concentration depended on whether the leak was in the flow path of ventilation and whether ventilation was directed or undirected. The concentration of leaks in the flow path was an order of magnitude lower than those not in the flow path and directed ventilation was much more effective at lowering the flammable concentration than undirected ventilation alone. The authors concluded that "the use of direct ventilation might provide a suitable way to increase safety without structural changes to the garage or ventilation system," but noted that better quantitative data is needed to perform a more robust risk assessment and that further research is required to inform a more complete understanding of the most effective ventilation configurations.

In a quantitative risk assessment published in June 2023, researchers assessed and quantified the risks and hazards posed by hydrogen forklifts (and, repurposed electric forklifts, in particular) and identified potential design recommendations to mitigate these risks [20]. The analysis focused on assessing the risks associated with a hydrogen release from the compressed hydrogen gas storage and delivery system of a fuel cell forklift and quantifying the potential harm that it could cause to the forklift driver. It did not assess the risks associated with the generation of hydrogen, on-site storage of hydrogen, or indoor refuelling systems, nor did it assess the inherent risks of forklifts generally [20]. The primary outcome of interest was fatalities among forklift operators. To assess risk, the researchers calculated the fatal accident rate (FAR) and the average individual risk (AIR) and compared these rates to levels of unacceptable risk for fatal injury in material-handling occupations [20]. FAR is defined as "the expected number of fatalities per 100 million exposure hours" and AIR is defined as "the average number of fatalities per exposed individual and is based on the duration of time the average occupant spends at a warehouse

facility." [20]. The levels of unacceptable risk were set as follows: FAR > 0.295 fatalities per 100 million hours-driver and AIR > 1 x 10^{-4} fatalities per forklift year [20]. The analysis, which focused on a generic Class I hydrogen fuel cell forklift modified from an electric forklift, assumed that the fuel cell and gas storage and delivery system was "enclosed, vented, and positioned in the electric battery compartment" and the piping in the hydrogen storage and delivery system was made to specifications "commonly used in hydrogen systems" [20]. The analysis also assumed "a single driver with a standard working schedule of 2000h per year" and that "the driver is positioned directly above the fuel cell system and about 1.035 m above the ground" [20]. A release of hydrogen from the onboard fuel storage and delivery system was the initiating event for all the scenarios modelled in the study. Based on their analyses and modelling, the researchers found that failure mainly occurred within the check valve, filter, and pressure relief devices in the gas storage and delivery system. They determined that the estimated frequency of hydrogen release was 1.82 × 10^{-2} and 1.80 × 10^{-2} events/forklift-year for a minor and major release scenario, respectively [20]. They further found that while the risk from minor releases was negligible, the risk of jet fires resulting from major releases was consequential [20]. Their FAR calculation for a hydrogen forklift generated a value 15 times higher than the level of unacceptable risk described above. The authors concluded that hydrogen forklifts could present a higher fire and explosion risk compared to current forklift technologies [20].

5 CSA B335, *Safety standard for lift trucks*

The third edition of CSA B335, *Safety standard for lift trucks,* sets out the key elements of a lift truck safety program, including competency requirements for operators, trainers, and maintenance technicians [36]. Requirements in this edition align with the design, classification, and maintenance requirements set out in ANSI/ITDSF B56.1, *Safety Standard for Low, High Lift Trucks,* and ANSI/ITDSF B56.6, *Safety Standard for Rough Terrain Forklift Trucks* [36]. ANSI/ITDSF B56.1 is briefly described in Appendix B1.1.

CSA B335 applies to the design, operation, and maintenance of six classes of powered lift trucks, Class 1 to Class 5, and Class 7 [36]. Certain clauses also apply to Class 6, non-powered high-lift trucks, and personnel and burden carriers [36]. The Standard, which is intended to promote lift truck safety and minimize the risk of injury to workers, can be used by Canadian regulators as a guide to develop and promulgate appropriate health and safety legislation and directives concerning lift trucks [36].

The Standard is organized into nine sections and includes six informative annexes [36].

- Sections 1 to 3 set out the scope of the Standard, list publications referenced in the Standard, and define the terms that apply in the Standard.
- Section 4 sets out the key elements of a safety program for lift truck users.
- Section 5 specifies the relevant clauses of ANSI/ITDSF B56.1 and ANSI/ITDSF B56.6 that lift trucks are to be designed and constructed in accordance with.
- Sections 6, 7, and 9 address operator training, lift truck trainer qualifications, and maintenance technician competency requirements, respectively.
- Section 8 outlines maintenance and repair practices to assist lift truck users and trained operators in maintaining their vehicles.

6 The Regulatory Landscape for Industrial Lift Trucks

6.1 Regulation of Industrial Lift Trucks in Canada

Operation of lift trucks in the workplace is regulated under the OHS legislative framework. In Canada, OHS falls under federal, provincial, or territorial authority, and responsibility for prevention and enforcement is either held by a government ministry or department (typically the Ministry of Labour) or by the agency responsible for the delivery of the workers' compensation system [88]. OHS provisions are found in specific statutes (i.e., the *Occupational Health and Safety Act or the Workers' Compensation Act*) and their subordinate regulations and are intended to establish a minimum level of protection for all workers or for those in specific



"All 14 Canadian jurisdictions have lift truck–specific regulations made pursuant to their respective Occupational Health and Safety Act."

industries. Typically, the OHS legislative and regulatory framework incorporates general duty clauses, as well as hazard-specific requirements, and sets out the parameters for enforcement and compliance that may be performance-based or prescriptive, depending on the hazard. A performance-based regulation is goal-oriented; it establishes the end point and allows the employer to identify the most suitable means of achieving it. A prescriptive regulation specifies both the end point and the means to achieve it.

All 14 Canadian jurisdictions have lift truck–specific requirements in regulations made pursuant to their respective *Occupational Health and Safety Act.* Two provinces (Manitoba and Ontario) have forklift-specific codes of practice. None specifically address hydrogen-powered forklifts. This section of the report summarizes key regulatory requirements that are pertinent to this project. Appendix A.3 lists the statutes and regulations reviewed for this project and includes pinpoints indicating the specific sections of the regulations examined.

6.1.1 Relevant Terms Defined in the OHS Regulations

Across Canada, seven terms are used to refer to industrial lift trucks: forklift, powered lift truck, mobile equipment, powered mobile equipment, prime mover, lifting device, and hoisting apparatus. As shown in Table 1, forklift is used and defined in three jurisdictions (Saskatchewan, Northwest Territories, and Nunavut); powered lift truck is used and defined in two jurisdictions (Manitoba and Ontario); lift truck is defined in one jurisdiction (Nova Scotia); mobile equipment is used and defined in three jurisdictions (British Columbia, Newfoundland and Labrador, and the Yukon); powered mobile equipment is used and defined in six jurisdictions (Alberta, Saskatchewan, Manitoba, Prince Edward Island, Northwest Territories, and Nunavut); prime mover is used and defined in two jurisdictions (British Columbia and Ontario); lifting device is used and defined in four jurisdictions (Saskatchewan, Ontario, Northwest Territories, and Nunavut); and hoisting apparatus is used and defined in two jurisdictions (Quebec and Prince Edward Island). Except for forklift, there is little consistency in how these terms are defined (see Table A.1-1 in Appendix A.1).

6.1.2 CSA Standard(s) Referenced in the OHS Regulations

Six of the fourteen Canadian jurisdictions reference CSA or ANSI lift truck standards in their OHS regulations (British Columbia, Manitoba, Quebec, Newfoundland and Labrador, Nova Scotia, and the Yukon). However, as shown in Table A.2-1 of Appendix A.2, the specific version of the standard that is referenced varies across jurisdictions.

- **CSA B335:** Five of the six jurisdictions (all but the Yukon) have incorporated by reference CSA B335 into their regulations. Of these, three jurisdictions reference a static edition of the standard (i.e., one

Table 1: Terms used in Canadian OHS Regulations to Refer to Industrial Lift Trucks

	BC	AB	SK	MB	ON	QC	NL	NS	NB	PE	YT	NT	NU	CA
Forklift			X									X	X	
Powered lift truck				X	X									
Lift truck								X						
Mobile equipment	X						X				X			
Powered mobile equipment		X	X	X						X		X	X	
Prime mover	X				X									
Lifting device			X		X							X	X	
Hoisting apparatus						X				X				

that existed on a particular date): British Columbia references the 2015 edition, Manitoba references the 2004 edition, and Quebec references the 1977 edition. The regulations in Quebec set out that lift trucks built before August 2, 2001, must comply with the 1977 edition of the standard. Two jurisdictions reference an ambulatory version of the standard (i.e., one that changes over time): Newfoundland and Labrador references CSA B335 without specifying the edition, while Nova Scotia references the latest edition.

In four of the five jurisdictions (all but Newfoundland and Labrador), the regulations that reference CSA B335 state that the design, fabrication, use, maintenance, and repair of a lift truck must meet the requirements of the Standard. The regulations in Newfoundland and Labrador state that the design, fabrication, use, inspection, and maintenance of a lift truck must meet the standard. Although they do not incorporate CSA B335 by reference into their regulations, the Northwest Territories and Nunavut do impose a general duty on (a) employers to ensure that every lifting device is "constructed, inspected, tested, maintained and operated in accordance with an approved standard" and (b) suppliers to ensure that every lifting device is "constructed, inspected, tested, and maintained in accordance with an approved standard." Section 1 of the regulations in Nunavut and the Northwest Territories define the meaning of "approved."

Two jurisdictions reference the operator training requirements of CSA B335 (British Columbia and the Yukon). Both are static references. British Columbia's regulations specify that operator training must meet the requirements in clause 6 of CSA B335-15, while the Yukon's regulations reference CSA B335-04.

- **ANSI B56.1:** Five of the six jurisdictions (all but Newfoundland and Labrador) have incorporated by reference either ANSI/ITSDF B56.1 or ANSI/ASME B56.1 into their regulations. Of these, three jurisdictions reference a static edition of the standard: British Columbia references the 2018 edition of ANSI/ITSDF B56.1a, the Yukon references the 2000 edition of ANSI/ASME B56.1, and Quebec references the 1993 version of ANSI/ASME B56.1. The regulations in Quebec set out that lift trucks built on or after August 2, 2001, must comply with the 1993 version of the standard. Two jurisdictions reference an ambulatory version of the standard: Nova Scotia references the latest version of ANSI/ITSDF B56.1 and the Manitoba Code of Practice references ANSI/ASME B56.1 without specifying the edition.

6.1.3 General Duties in Relation to Forklifts

The regulators in each Canadian jurisdiction have general duty clauses in their governing statutes or subordinate regulations that require employers to provide workers with a safe work environment

that is free of recognized hazards. In addition, eight Canadian jurisdictions have general duty provisions in their regulations regarding design, operation, and maintenance of forklifts (Ontario, Quebec, Newfoundland and Labrador, Nova Scotia, New Brunswick, Prince Edward Island, Northwest Territories, and Nunavut). The Northwest Territories and Nunavut are the only jurisdictions that impose a general duty on suppliers regarding forklifts.

- **Ontario:** R.R.O. 1990, Reg 851 includes a general provision that a lifting device is to be "constructed so as to adequately ensure the safety of all workers."
- **Quebec:** CQLR c S-2.1, r 13 includes a general provision that "every hoisting device shall be used, maintained, and repaired in such a manner that its use does not compromise the health, safety or physical well-being of workers."
- **Newfoundland and Labrador:** NLR 5/12 includes a general provision that "mobile equipment shall be maintained in safe operating condition and operation."
- **Nova Scotia:** N.S. Reg. 53/2013 includes a general provision that an employer must ensure that a lift truck is "erected, installed, assembled, started, operated, used, handled, stored, stopped, inspected, serviced, tested, cleaned, adjusted, maintained, repaired, modified and dismantled in accordance with the manufacturer's specifications, or the specifications certified by an engineer." The regulations also include a general provision that employers must ensure that "a lift truck is operated in a manner that will not endanger a person."
- **New Brunswick:** NB Reg 91-191 includes a general provision that an employer must ensure a lift truck "is only used for purposes for which it was designed."
- **Prince Edward Island:** PEI Reg EC180/87 includes a general provision that the employer shall ensure that powered mobile equipment is "maintained in a safe operating condition and that the operation, inspection, repair and maintenance of the equipment, and any necessary modifications to the equipment, are carried out in accordance with the manufacturer's instructions or, in the absence of those instructions, as approved by a professional engineer" and "used exclusively for the purposes for which the equipment is designed and equipped."
- **Northwest Territories and Nunavut:** NWT Reg 023-2015 and C.R.Nu. R-003-2016 impose general duties on the employer and on suppliers. The general duty imposed on employers is that they shall ensure that every lifting device used at a work site is "designed, constructed, installed, maintained and operated to perform safely those tasks for which it is used." Similarly, the general duty imposed on suppliers is that they shall ensure that every lifting device supplied for use at a work site is "designed, constructed, installed, maintained and operated to perform safely those tasks for which it is intended to be used."

6.1.4 Operator Training and Competency Requirements

All fourteen Canadian jurisdictions have requirements in their OHS regulations for forklift operator training and competency (see Table A2.2 in Appendix A.2). British Columbia incorporates a static reference to the operator training requirements of CSA B335-15 into their regulations.

While most jurisdictions require that forklift operators be trained and have competency, there are some inconsistencies in the regulations across the country. Quebec is the only jurisdiction in Canada that sets out a minimum age for forklift operators, and Manitoba is the only province that requires employers to issue certificates to workers who have received training and demonstrated competency. Three jurisdictions have general requirements that forklifts are only to be operated by a competent person or a worker being instructed by a competent person (Ontario, Quebec, and Newfoundland and Labrador). Nine jurisdictions impose obligations on employers to ensure competency (Alberta, Saskatchewan, Manitoba, Nova Scotia, New Brunswick, Prince Edward Island, Northwest Territories, Nunavut, and the federal government), two impose similar obligations on supervisors (Newfoundland and the Yukon), and six impose obligations on workers to not operate forklifts unless they have been properly trained (Alberta, Saskatchewan, Newfoundland and Labrador, the Yukon, Northwest Territories, and Nunavut). Only two jurisdictions (Manitoba and the federal government) have requirements that employers keep records of operator training.

6.1.5 Inspection and Monitoring Requirements

Ten of the fourteen Canadian jurisdictions have requirements in their OHS regulations for forklifts to be inspected before they are used for the first time, before they are first operated on a shift, and as required on an ongoing basis (see Table A.2-3 in Appendix A.2) Alberta, Saskatchewan, Manitoba, and Nova Scotia have no explicit requirements in their regulations for pre-use and routine inspections. However, the Manitoba Code of Practice For the Safe Operation of Powered Lift Trucks recommends that employers allow inspection, testing, and maintenance to be performed only by qualified, trained, and experienced persons, and that a record be kept at the workplace.

While the intent of the inspection requirements is similar in the 10 jurisdictions, there are some inconsistencies in how the regulations are worded. Only eight jurisdictions explicitly require that forklift inspection and repair be performed by a competent or qualified person (Alberta, Saskatchewan, Manitoba, Ontario, New Brunswick, Northwest Territories, Nunavut, and the federal government). Five jurisdictions require that records be kept (Alberta, Saskatchewan, Manitoba, Ontario, and the federal government). Of these, only Ontario and the federal government have requirements that the inspection records be signed by the person doing the inspection and kept by the employer.

6.1.6 Maintenance Requirements

Nine of the fourteen Canadian jurisdictions have requirements in their OHS regulations for forklift modification and maintenance that are relevant to this project (see Table A.2-4 in Appendix A.2). The regulations in four jurisdictions (Saskatchewan, Manitoba, Newfoundland and Labrador, and the Yukon) set out that any modifications and/or additions are to be performed in accordance with the manufacturer's instructions or with the written approval of the manufacturer or a professional engineer qualified in the work. The federal regulations set out that any modification or replacement of a part of a forklift is to at least maintain the safety factor of the original part. The regulations in five jurisdictions (British Columbia, Alberta, Newfoundland and Labrador, the Yukon, and the federal government) include requirements for recordkeeping of maintenance and modification.

6.1.7 Fuel-related Requirements

Eight of the fourteen Canadian jurisdictions have requirements related to forklift fuel, fuel tanks, and refuelling (see Table A.2-5 in Appendix A.2). British Columbia is the sole jurisdiction that prohibits a fuel tank fill point or vent opening within the enclosed cab of mobile equipment, while Alberta and Saskatchewan require an employer to ensure that a fuel tank located in an enclosed cab have a filler and vents that extend outside the cab. The regulations in five jurisdictions (Alberta, Ontario, Quebec, Prince Edward Island, and the federal government) set out requirements for refuelling. While most apply to gasoline engines, some are relevant to hydrogen-powered forklifts. For example, Alta Reg 191/2021 prohibits (a) smoking within 7.5 metres of vehicle while it is being refuelled and (b) refuelling when there is an ignition source within 7.5 metres of the vehicle; R.R.O. 1990, Reg 851 requires that the forklift be refuelled outdoors with no source of ignition within three metres of the dispensing point; PEI Reg EC180/87 requires that the operator must follow a safe refuelling procedure; and the federal government requires that when a forklift is fuelled in a workplace, it must be fuelled by a qualified person in accordance with safe procedures in a well-ventilated place so that the fuel vapours will dissipate quickly. The regulations in two jurisdictions (Nova Scotia and the federal government) also set out requirements for the design, operation, and maintenance of propane-propelled forklifts and incorporate by reference the relevant CSA standards.

The federal government is the only jurisdiction with a regulation that applies to a hazardous substance contained in a fuel tank, compressed gas cylinder, other container, or any associated assembly mounted on motorized materials-handling equipment. It imposes an obligation on the employer to ensure that the tank, cylinder, container, or assembly is (a) located or guarded in such a way as to protect a worker who is required to operate or ride on the equipment, (b) connected to fuel overflow and vent pipes that are located in such a way as to prevent ignition of fuel spills and vapours, and (c) labelled on its servicing caps or covers as to its contents.



"Like Canada, operation of lift trucks in the workplace is regulated under the OHS legislative framework in the US, the European Union, the United Kingdom, and Australia."

6.2 Regulation of Lift Trucks in Select International Jurisdictions

Like Canada, operation of lift trucks in the workplace is regulated under the OHS legislative framework in the US, the European Union, the United Kingdom, and Australia. While each of these jurisdictions had a hydrogen strategy that articulates how and why hydrogen is a central component of their decarbonization and clean energy efforts, none of the OHS regulations specifically address hydrogen-powered forklifts.

6.2.1 United States

The US Occupational Safety and Health Administration (OSHA) issues standards that outline rules that employers must comply with to protect worker health and safety. OSHA Standard 1910.178 covers the requirements for powered industrial trucks and requires that they meet the 1969 version of ANSI B56.1 [89]. OSHA Standard 1910.178 includes requirements for use of converted industrial trucks, fuel handling and storage of liquid fuels (which must comply with relevant NFPA standards), refuelling and/or charging storage batteries, and operator training and evaluation [89]. It does not, however, address compressed gas hydrogen (CGH) types of vehicles. Although OSHA does not have specific requirements or guidelines for hydrogen-powered forklifts, it does provide information on its website about the hazards of "green jobs" in a range of industries, including the fuel cell industry [90]. Green jobs are broadly defined as those that help to improve, preserve, or restore the environment.

6.2.2 European Union

The European Union has directives and regulations on the design and use of machinery used by workers in the European Union, as well as a guidance document comparing national practices on the use of forklifts for lifting workers. No regulation or guidance explicitly addresses the use of hydrogen-powered forklifts.

- **Directive 2009/104/EC** sets out minimum requirements for the use of work equipment at work, generally and in specific circumstances (e.g., working at height, using mobile work equipment, using equipment for lifting loads) [91].
- **Directive 2006/42/EC** imposes duties on equipment manufacturers to ensure conformity with provisions in the Directive and sets out essential requirements for the design and construction of machinery, interchangeable equipment, safety components, lifting accessories, chains, ropes and webbing, removable mechanical transmission devices, and partly completed machinery used in the European Union [92]. Directive 2006/42/EC was repealed in 2023 and replaced with Regulation 2023/1230/EU, which comes into effect in January 2027 [93]
- **Regulation 2023/1230/EU** sets out the mandatory essential requirements for the design and construction of machinery in order for it to be placed on the European Union market and the procedures by which conformity with the regulation is assessed [93, 94].

Although there are no specific regulations or guidelines for hydrogen-powered forklifts in the European Union, the European Agency for Safety and Health at Work (EU-OSHA) does provide information on its website about health and safety in green jobs, which contribute to preserving or restoring the environment and encompass a "broad range of jobs in different sectors, with different working conditions and working processes and involving a diverse workforce" [95, 96]. At present, EU-OSHA provides information on emerging risks in these jobs, as well as practical information (in the form of e-bulletins and hazard checklists) on preventing and mitigating risk in jobs related to small-scale solar energy applications, green buildings, and wind energy [95].

6.2.3 United Kingdom

The Health and Safety Executive (HSE) in the United Kingdom has enacted two pieces of legislation relevant to this project: *Lifting Operations and Lifting Equipment Regulations 1998* (LOLER) [97] and *Provision and Use of Work Equipment Regulations 1998* (PUWER) [98]. The former, which regulates lifting operations, including forklifts, sets up the legal framework for enforcement by the regulator and identifies "dutyholders" responsible for elements of compliance [99]. The latter, which imposes requirements on "people and companies who own, operate or have control over work equipment," sets out that equipment must be suitable for its intended use, maintained in a safe condition, regularly inspected, used by people properly trained on its use in normal conditions, and what to do in abnormal situations [98]. To supplement and support these regulations, the HSE has published three Approved Codes of Practice (ACOP) and guidance. An ACOP describes the preferred or recommended method to comply with the regulation in relation to the given topic.

- **ACOP for Safe Use of Lifting Equipment:** This document addresses the safe use of lifting equipment, including forklifts [99]. The term "hydrogen" appears in the document in the context of "hydrogen embrittlement," which is defined as "the action of hydrogen on some classes of steel that can weaken it, making it more likely to fail" [99]. Hydrogen cracking and embrittlement are highlighted in a section on material of manufacture as examples of what can occur if "certain grades of high tensile steels are exposed to acid or alkaline atmospheres" [99]. This section of the ACOP provides guidance on how to select lifting equipment made of materials suitable for the conditions under which it will be used and lays out what should be included in a risk assessment [99]. There is no mention in the ACOP of hydrogen fuel cells or refuelling of a hydrogen-powered forklift.
- **ACOP for Rider-Operated Lift Trucks – Operator Training:** This document focuses on the training requirements for lift truck operators [100]. Hydrogen is mentioned in the context of battery care and maintenance of electrically powered lift trucks. The ACOP notes that hydrogen is given off when batteries (including those described as "maintenance free") are charged, highlights the hazard (i.e., the hydrogen gas and the battery will explode if there is a source of ignition), and provides guidance on instructing and training operators, as well as what to do when charging vehicle batteries [100]. The document discusses lift truck power sources (i.e., electric batteries, internal combustion engines), but does not explicitly mention hydrogen or hydrogen fuel cells. The guidance on refuelling only addresses refuelling lift trucks with internal combustion engines [100].
- **ACOP for Safe Use of Work Equipment:** This document sets out what people and companies who own, operate, or have control over work equipment need to do to comply with PUWER [101]. Although the ACOP addresses lift trucks, it does not provide any guidance on hydrogen-powered forklifts.

6.2.4 Australia

Safe Work Australia develops model Work Health and Safety laws (which include the model *Work Health and Safety Act,* Regulations, and Codes of Practice) for adoption, modification as required, and implementation by the Australia Commonwealth, states, and territories [102]. The model laws are intended to provide the foundation for nationally consistent OHS laws, but are not legally binding on their own [102, 103]. They become legally enforceable in a jurisdiction when that jurisdiction promulgates them as law [102]. Schedule 3 to the *Model Work Health and Safety Regulations* lists

forklifts as part of high-risk work requiring a licence [103]. Schedule 11 regulates hazardous chemicals and lists fuel in gaseous or liquid form requiring special handling [103]. However, "hydrogen" or "fuel cell" is not identified or addressed in the Model Regulations.

Model Codes of Practice have been developed to address common workplace health and safety incidents across all states and territories in Australia [104]. There are no stand-alone model Codes of Practice for forklift operation or refuelling. The term "forklift" does appear in some Codes of Practice, such as "Managing the risk of falls at workplaces" and "Managing risks in stevedoring" [105, 106]. However, the term appears in the context of particular hazards, like, for example, using a workbox or a work platform attached to a forklift to create an elevated work area [105]. "Forklift" or "industrial truck" does not appear in the context of fuel handling safety or powertrain energy sources.

7 Review of CSA B335 and Relevant Safety Standard for Lift Trucks

Each clause in CSA B335 was critically examined to determine whether it involved fuel or fuel considerations, and whether (and how) the use of hydrogen as a forklift power source might have an impact on the language in the current Standard. Where a potential impact was identified, relevant standards were consulted to determine whether and how it might be addressed. The outcome of this review then informed a series of recommendations for consideration by the Technical Committee for CSA B335. This section of the report discusses what was learned in the review of the Standard and identifies areas of the Standard where amendments or explanatory notes could address hydrogen-powered forklifts.

7.1 Lift Truck and Hydrogen Standards Consulted

This section of the report briefly describes relevant standards addressing lift trucks, hydrogen, and hydrogen-powered forklifts that were consulted as part of the review of CSA B335.

7.1.1 ANSI/ITSDF B56.1, *Safety Standard for Low Lift and High Lift Trucks*

ANSI/ITSDF B56.1, *Safety Standard for Low Lift and High Lift Trucks,* is part of the B56 suite of standards for powered and non-powered industrial trucks administered by the Industrial Truck Standards Development Foundation (ITSDF) [107-108]. It sets out requirements for the "design, operation, and maintenance of low lift and high lift powered industrial trucks controlled by a riding or walking operator, and intended for use on compacted, improved surfaces" [107].

The terms "hydrogen" or "hydrogen fuel cell" appear in two parts of the Standard. Hydrogen is mentioned in two clauses: the first is in the context of operator care of the truck, and the second is in the context of maintenance and inspection of powered industrial trucks and attachments. Hydrogen fuel cell is included as an example of an electric power source in the definition of "source, electric power," which is defined as "a device/system that provides electric energy to the truck" [107].

7.1.2 NFPA 505, *Fire Safety Standard for Powered Industrial Trucks*

NFPA 505, *Fire Safety Standard for Powered Industrial Trucks Including Type Designations, Areas of Use, Conversions, Maintenance, and Operations,* sets out comprehensive requirements and fire safety guidance for industrial trucks powered by ICEs and electric motors, including compressed gaseous hydrogen fuel cell systems [109]. It applies to "fork trucks, tractors, platform lift trucks, motorized hand trucks, and other specialized trucks powered by electric motors or internal combustion engines"; it does not apply to "compressed air-operated or nonflammable compressed gas-operated industrial trucks, farm vehicles, or automotive vehicles for highway use" [109].

Hydrogen-powered forklifts were first addressed in the 2011 edition of the Standard when the Standard's application was expanded to include fuel cell systems and conversions. The requirements for industrial trucks powered by hydrogen fuel cell systems were subsequently expanded in the 2013 edition of the Standard.

7.1.3 NFPA 2, *Hydrogen Technologies Code*

NFPA 2, *Hydrogen Technologies Code,* sets out "fundamental safeguards for the generation, installation, storage, piping, use and handling of hydrogen in compressed gas (GH_2) form or cryogenic liquid (LH_2) form" [43]. It applies to the "production, storage, transfer, and use of hydrogen"; it does not apply to "the design or components related to the transport of hydrogen or propulsion of hydrogen motor vehicles, including onboard hydrogen storage systems," "mixtures of GH_2 and other gases with a hydrogen concentration of less than 95 percent by volume when in accordance with NFPA 55," and "the storage, handling, use, or processing of metal hydride materials outside of metal hydride storage systems defined in Chapter 3" [43]. Requirements for hydrogen-powered industrial trucks (HPITs) were created for the 2023 edition of the Code.

7.1.4 UL 2267, *Fuel Cell Power Systems for Installation in Industrial Electric Trucks*

UL 2267, *Fuel Cell Power Systems for Installation in Industrial Electric Trucks,* sets out requirements for the construction and performance of both purpose-built and converted hydrogen fuel cell–powered industrial trucks, as well as manufacturing and production tests for quality assurance [110]. It applies to "fuel cell power systems intended to be installed in Type E, Type CGH, Type CGH-EE, Type CGH-ES, or Type CGH-EX industrial trucks" used in locations defined in NFPA 505, NFPA 70, and UL 583 (which is briefly described below in 7.1.5).

Fuel cell power systems covered by the Standard are anticipated for use as described in ANSI/ITSDF B56.1 and other standards in the B56 suite of standards. UL 2267's requirements cover "fuel cell power systems that incorporate a permanently mounted pressure vessel containing compressed hydrogen gas," "the use of designs that are fueled by hydrogen gas without the pressure vessel being removed from the industrial truck (onboard fueling)," and "only the fuel cell and fuel cell balance of plant components including the power and/or power conditioning electronics, regardless of packaging" as defined in the standard "as well as any components in classified zones" [110].

7.1.5 ANSI/CAN/UL 583, *Electric-Battery-Powered Industrial Trucks*

ANSI/CAN/UL 583, *Electric-Battery-Powered Industrial Trucks,* addresses fire, electric shock, and explosion hazards for electric battery-powered industrial trucks; it does not address other possible hazards or risks associated with the use of such trucks [111]. The Standard applies to "tractors, platform-lift trucks, fork-lift trucks, and other vehicles designed for specific industrial uses" [111]. It covers (a) power sources intended for use in the types of electric battery-powered industrial trucks specified in the Standard and (b) Types E, CGH, E or CGH, EE, ES, and EX electric-powered industrial trucks [111].

7.1.6 SAE J2601/3, *Fueling Protocol for Gaseous Hydrogen Powered Industrial Trucks*

SAE J2601/3, *Fueling Protocol for Gaseous Hydrogen Powered Industrial Trucks,* establishes requirements for gaseous hydrogen fuel dispensers used to fuel hydrogen-powered forklifts and other hydrogen-powered industrial trucks [112]. The Protocol applies to hydrogen-powered industrial trucks, which includes "utility vehicles, fork lifts, tugs, and other electric vehicles using H2 fuel cell battery replacement modules (BRMs)" and "can support a wide range of hydrogen fuel cell hybrid electric vehicles including fork lifts, tractors, pallet jacks, on and off road utility, and specialty vehicles of all types" [112]. The Protocol, which is "suitable for all vehicle tank fueling systems above 18 L water volume and may be used for fueling of all types of Hydrogen Powered Industrial Trucks (HPITs) and Battery Replacement modules (BRMs)," describes three fuel dispensing methods: fill to service pressure with fixed area flow-limiting device, fill to target pressure with fixed area flow-limiting device, and fill to targe pressure with variable area flow-limiting device [112]. It is aimed at fueling system builders, suppliers, and operators, and is intended to provide guidance for a performance-oriented dispenser fuelling protocol for hydrogen-powered industrial trucks.

7.2 Outcome of the Review of CSA B335

The review of CSA B335 identified a number of areas where the Standard could be amended or where explanatory notes could be added to address hydrogen-powered forklifts. These potential amendments and explanatory notes are discussed below and are synthesized in tabular form in Appendix B (Table B.1.1).

7.2.1 Reference Publications

Three of the six standards reviewed for this project are listed in Section 2 of CSA B335 (Reference Publications). The following three standards are not referenced publications in CSA B335: UL 2267, NFPA 2, and SAE J2601/3. The review of these three standards, along with five of CSA Group's hydrogen vehicle requirements standards, is recommended for consideration. The five CSA standards, which were not reviewed as part of this project, are: CSA/ANSI HGV 2, CSA/ANSI HGV 3.1, CSA/ANSI HPRD 1, CSA HPIT 1, and CSA HPIT 2.

7.2.2 Definitions

All six standards reviewed define terms that are relevant to this project.

- ANSI/ITSDF B56.1 includes "hydrogen fuel cell" as an example of an electric power source in the definition of "source, electric power" [107].
- NFPA 505 includes compressed gaseous hydrogen-powered industrial trucks in its definition of "Type Designation," which is defined in 3.3.2 as "a system for identifying types of powered industrial trucks for operation in nonclassified and classified areas." These units are assigned a Type Designation CGH and are defined in Section 3.3.2.1 as a "compressed hydrogen powered unit utilizing a fuel cell that has minimum acceptable safeguards against inherent fire and electrical shock hazards" [109].
- NFPA 2 defines the following 13 relevant terms:
  - Fuel supply container: Defined in Section 3.3.50.2 as "a container mounted on a vehicle to store LH_2 or CH_2 as the fuel supply to the vehicle" [43].
  - Fuel cell cartridge: Defined in Section 3.3.97 as "a removable article that contains and supplies fuel to the micro fuel cell power unit or internal reservoir" [43].
  - Fuel cell power system (FCPS): Defined in Section 3.3.237.9 as "a generator system that converts the chemical energy of reactants (a fuel and an oxidant) by an electrochemical process to electrical energy (direct current or alternating current electricity) and thermal energy" [43].
  - Fuel line: Defined in Section 3.3.100 as "the pipe, tubing, or hose on a vehicle, including all related fittings, through which hydrogen passes during normal vehicle fueling or operation" [43].
  - Gas detection system: Defined in Section 3.3.237.10 as "one or more sensors capable of detecting hydrogen at specified concentrations and activating alarms and safety systems" [43].
  - Gas room: Defined in Section 3.3.111 as "a separately ventilated, fully enclosed room in which only compressed gases, cryogenic fluids, associated equipment, and supplies are stored or used" [43].
  - Gaseous hydrogen (GH_2) system: Defined in Section 3.3.237.11 as "an assembly of equipment that consists of, but is not limited to, storage containers, pressure regulators, pressure relief devices, compressors, manifolds, and piping and that terminates at the source valve" [43].
  - GH_2: Defined in Section 3.3.115 as "hydrogen in the gas phase" [43].
  - Hydrogen-powered industrial truck (HPIT): Defined in Section 3.3.125 as "hydrogen-powered vehicles including lift trucks, motorized hand trucks, and other specialized industrial trucks" [43].
  - Qualified individual: Defined in Section 3.3.208 as "an individual knowledgeable in the hazards of compressed gases and cryogenic fluids through training and work experience" [43].
  - Qualified person: Defined in Section 3.3.209 as "a person who, by possession of a recognized degree, certificate, professional standing, or skill, and who, by knowledge, training, and experience, has demonstrated the ability to deal with problems relating to a particular subject matter, work, or project" [43].
  - Repair garages: Section 3.3.214 of the Code distinguishes between major repair garages and minor repair garages for hydrogen vehicles. The former is defined in Section 3.3.214.1 as "a building or portions of a building for major repairs, such as work on the hydrogen storage system, the fuel system, repairs that require defueling of the hydrogen vehicle, and maintenance or repairs that require open-flame

cutting or welding" [43]. The latter is defined in Section 3.3.214.2 as "a building or portions of a building used for lubrication, inspection, and minor automotive maintenance work, such as engine tune-ups, replacement of parts, fluid changes (e.g., brake fluid, air conditioning refrigerants), brake system repairs, tire rotation, and similar maintenance work" [43].

- User (Dispenser): Defined in Section 3.3.249 as "a person who uses a dispenser to fuel a motor vehicle who might or might not be trained" [43].

- UL 2267 defines the following 11 relevant terms:
  - Fuel cell power system: Defined in Section 5.7 as "an assembly of components and parts that together electrochemically converts fuel and oxidant to electrical current" [110]. Section 5.7 goes on to list the forms in which the fuel cell power system will be in for use with industrial trucks. These include self-contained system, integrated system, Type CGH-E fuel cell power system, Type CGH-EE fuel cell power system, Type CGH-ES fuel cell power system, and Type CGH-EX fuel cell power system [110].
  - Self-contained system: Defined in Section 5.7 as "a complete system incorporated into its own housing that is intended to replace or combine with a battery system to power an industrial truck. Additional counterweighting may be located outside of the system's housing. Display and control functions may be located outside the system's housing in proximity to the operator's compartment" [110].
  - Integrated system: Defined in Section 5.7 as " a complete system of fuel cell components and parts that are incorporated into the industrial truck with the various parts of the system potentially distributed throughout the truck" [110].
  - Type CGH-E fuel cell power system: Defined in Section 5.7 as "a fuel cell power system intended for use in Type E industrial trucks only" [110].
  - Type CGH-EE fuel cell power system: Defined in Section 5.7 as "a fuel cell power system intended for use in Type EE industrial trucks that, in addition to meeting all the requirements for a Type CGH-E and Type CGH-ES units, has its electric motors and all other electric equipment completely enclosed" [110].
  - Type CGH-ES fuel cell power system: Defined in Section 5.7 as "a fuel cell power system intended for use in Type ES industrial trucks that, in addition to meeting all the requirements for a Type CGH-E units, is provided with additional safeguards to the electric system to prevent the emission of hazardous sparks and to limit surface temperatures" [110].
  - Type CGH-EX fuel cell power system: Defined in Section 5.7 as "a fuel cell power system intended for use in Type EX industrial trucks that, in addition to meeting all the requirements for a Type CGH-E units, has electric fittings and equipment so designed, constructed, and assembled that the unit can be used in atmospheres containing specifically named flammable vapors, dusts, and under certain conditions, fibers" [110].
  - Type CGH industrial truck: Defined in Section 5.30 as "an electrically operated industrial truck that utilizes a compressed hydrogen powered unit utilizing a fuel cell for conversion of the hydrogen fuel gas to electricity that has minimum acceptable safeguards against inherent fire hazards" [110].
  - Type CGH-EE industrial truck: Defined in Section 5.31 as "a type EE industrial truck that utilizes a Type CGH-EE fuel cell power system" [110].
  - Type CGH-ES industrial truck: Defined in Section 5.32 as "a type ES industrial truck that utilizes a Type CGH-EE fuel cell power system" [110].
  - Type CGH-EX industrial truck: Defined in Section 5.33 as "a type EX industrial truck that utilizes a Type CGH-EE fuel cell power system" [110].
- ANSI/CAN/UL 583 includes definitions for Type CGH, Type E, Type E or CGH trucks and defines them as follows:
  - Type CGH: A compressed hydrogen-powered unit utilizing a fuel cell that has minimum acceptable safeguards against inherent fire and electric shock hazards [111].
  - Type E: An electrically powered unit that has minimum acceptable safeguards against inherent fire and electric shock hazards [111].
  - Type E or CGH: A unit that has met all the requirements for both a Type E and Type CGH [111].
- SAE J2601/3 defines 35 terms and lists abbreviations and symbols used in the Standard [112]. Defined terms are organized under six headings:
  - Hydrogen-powered industrial truck: Three terms are defined. They are battery replacement module, hydrogen-powered industrial truck, and receptacle.

- Capacity: Three terms are defined. They are fast fuelling, storage capacity, and slow fuelling.
- Dispenser Components: Six terms are defined. They are breakaway, communication connector, dewatering connector, dispenser, hydrogen supply system, and nozzle.
- Temperature: Five terms are defined. They are ambient temperature, bulk hydrogen temperature, calculated temperature of vehicle storage tank, fuel delivery temperature, and vehicle tank gas temperature.
- Pressure: Thirteen terms are defined. They are compensated fill pressure, initial tank pressure, integrity check, maximum allowable work pressure, maximum vehicle pressure drop, overpressure protection system, pressure safety valve (PSV)/ pressure activated pressure relief valve, nominal working pressure, vehicle tank pressure, target fill pressure, service pressure, settled pressure, and pressure class.
- State of Charge: One term is defined, and a standardized equation is provided.

None of the terms identified above are defined in CSA B335. The addition of the following terms and definitions to this section of the Standard is recommended for consideration by the Technical Committee: hydrogen-powered industrial trucks, hydrogen gas vehicle, compressed gas hydrogen, compressed hydrogen, fuel cell power system, fuel cell electric vehicle, and battery replacement module.

7.2.3 General Requirements

All six standards reviewed include general requirements for hydrogen-powered forklifts that are not addressed in CSA B335.

- ANSI/ITSDF B56.1: Clause 5.5.6 advises the operator to not use open flames when checking hydrogen fuel lines and connectors, and Clause 6.2.4 advises against using an open flame to check the level or for leakage of hydrogen [107]. Part II of the Standard addresses the storage and handling of liquid fuels and liquified petroleum gas fuels in Clause 4.6 (by reference to ANSI/NFPA Standards 505 and 30) but does not address the safe handling of gaseous fuels. Issues related to electric power sources (i.e., changing and charging facilities, safe operating procedures) are addressed by reference to ANSI/NFPA Standard 505 [107]. No additional information is provided to manufacturers in Part III regarding specific requirements for hydrogen-powered industrial trucks and no obligation is imposed on them to provide information on the hazards associated with hydrogen release in enclosed spaces.
- NFPA 505: Chapters 4 and 5 address the classification of locations in which industrial powered trucks are permitted to be used. Chapter 4 sets out that hazardous locations are to be classified in accordance with NFPA 70, *National Electrical Code* [109]. Under the Standard, Type CGH powered trucks are not permitted in Class I (Division 1 and Division 2), Class II (Division 1 and Division 2), or Class III (Division 1) locations [109]. They are authorized for Unclassified (Ordinary) locations, as well as Class III, Division 2 locations with the approval of the authority having jurisdiction [109]. Chapter 9 includes requirements for fuel handling and storage, changing and charging storage batteries, changing Type CGH battery replacement modules, marking and labelling, safe operating rules, and operating procedures and training [109]. Sections 9.1.3.2 and 9.1.3.4 respectively require that the "compression, storage, handling and dispensing of compressed hydrogen gas (CGH) be located and conducted in accordance with NFPA 2," and that the operator not be in the normal operating position while refuelling [109]. This section of the Standard requires that (a) each fuel supply container be mounted in a location that minimizes damage from collision; (b) a container and its fittings not extend beyond the plan form of the truck; (c) containers, valves, hoses, and fittings be protected from physical damage in accordance with NFPA 2 (i.e., using the vehicle structure, valve protectors, suitable guards); and (d) the truck's refuelling receptacle be firmly supported and incorporate a means to prevent the entry of foreign material [109]. The Standard requires that the transfer of CGH into an industrial truck's fuel supply container be performed by "a person who has performed the transfer operation for at least three full cycles under supervision and who has competence in initiating emergency procedures" [109]. This chapter also includes prohibitions on smoking and open



"All six standards reviewed include general requirements for hydrogen-powered forklifts that are not addressed in CSA B335."

flames in the refuelling area and the use of a match or open flame to check for leaks in CGH fuel systems.

Section 9.4 sets out requirements for changing Type CGH battery replacement modules [109]. This section applies to replaceable fuel cell system modules in Type CGH trucks and to fuel cell modules used to replace batteries in electric (i.e., Type E) trucks [109]. In addition to requirements for chain hoists and spreader bars and a prohibition on smoking in Type CGH areas, the Standard requires that trained and authorized personnel change the fuel cell system modules and that precautions be taken to prevent open flames, sparks, or electric arcs [109].

Section 9.5 sets out marking and labelling requirements for a range of industrial truck types, but it does not address Type CGH trucks. Section 9.6 requires that the operation of powered industrial trucks comply with the applicable sections of ANSI/ITDSF B56.1 [109]. This section of the Standard requires that an operator perform a pre-shift inspection, including a visual check of the truck's general condition and "a check for the presence of easily ignited combustible materials such as accumulated debris and oily rags" [109]. The Standard does not require that the pre-shift inspection include a check for the detection of hydrogen leaks.

- NFPA 2: Chapters 4, 5, and 6 address general fire safety requirements, general hydrogen requirements, and gaseous hydrogen requirements, respectively. Chapter 4 sets out goals and objectives aimed at providing a "reasonable level of safety, property protection, and public welfare from the hazards created by fire, explosion, and other hazardous conditions" [43]. Section 4.4 provides the user with a choice of prescriptive or performance-based compliance. Users choosing the prescriptive-based option must comply with Chapters 1 through 4 and 6 through 18, as applicable; users choosing the performance-based option must comply with Chapters 1 through 5 of the Code [43]. Chapter 5 sets out the requirements that occupancies containing gaseous hydrogen must comply with in addition to other applicable requirements in the Code [43]. These include requirements for design and construction; control areas;[1] occupancy classification; piping; gas rooms; weather protection; electrical equipment; employee alarm system; explosion control; fire protection systems; gaseous hydrogen detection systems; lighting; spill control, drainage, and secondary containment; shelving; vent system termination; gas cabinets; exhausted enclosures; source valve; and cleaning, purging, and repairing of piping systems [43]. Chapter 7 sets out the

[1] Defined in Section 3.3.7.1 as "a building or portion of a building or outdoor area within which hazardous materials are allowed to be stored, dispensed, used or handled in quantities not exceeding the MAQ". MAQ (maximum allowable quantity per control area) is defined in Section 3.3.150 as "a threshold quantity of hazardous material in a specific hazard class that once exceeded requires the application of additional administrative procedures, construction features, or engineering controls."

requirements that the storage, use, and handling of GH2 must comply with, in addition to other applicable requirements in the Code [43]. Chapter 10 sets out the requirements that apply to the design, construction, and installation of GH_2 systems utilized for vehicle refuelling [43]. Section 10.1.1 clarifies that these requirements "apply to fueling operations, irrespective of the system capacity of either the fueling source or the vehicle being fueled," while Section 10.1.2 makes explicit that the storage, use, and handling of GH_2 in any quantity must also comply with the requirements of Chapters 1 and 4, as well as the applicable requirements of Chapters 5 through 7 [43]. The requirements in this chapter address design, installation, dispensing, maintenance, compact hydrogen fuelling systems, outdoor nonpublic home fuelling appliances, outdoor nonpublic mobile fleet fuelling, and on-demand mobile fuelling [43].

- Chapter 19 of NFPA 2 sets out the requirements that apply to the design, construction, and use of hydrogen-powered industrial trucks [43]. Sections 19.2.1 and 19.2.2 require that hydrogen-powered industrial trucks comply with NFPA 505 and that fuel cell power systems for hydrogen-powered industrial trucks must be listed to UL 2267 or approved [43]. Section 19.4 sets out that hydrogen-powered industrial trucks are to be fuelled in accordance with Section 10.5.3.2 and either Section 10.5.3.3 or Section 10.5.3.4 of the Code [43].
  - Section 10.5.3.2 – Gas dispensing equipment for HPITs: This section has three subsections. Section 10.5.3.2.1 requires that gas-dispensing equipment for hydrogen-powered industrial trucks be listed to CSA HPIT 2, *Dispensing systems and components for fueling hydrogen powered industrial trucks,* or approved. Section 10.5.3.2.2 and 10.5.3.2.3 distinguish between dispensing equipment for slow-fill vs. fast-fill of hydrogen-powered industrial trucks. The former requires that slow-fill gas dispensing equipment for hydrogen-powered industrial trucks use the fuelling protocol of SAE J2601-3, *Fueling Protocol for Gaseous Hydrogen Powered Industrial Trucks,* or comply with Clause 10 of CSA HPIT 2 (i.e., the design by rule for hydrogen-powered industrial truck dispensers) to limit the fuelling rate [43]. The latter requires that fast-fill gas dispensing equipment for hydrogen-powered industrial trucks use the fuelling protocol of SAE J2601-3 [43].
  - Section 10.5.3.3 – Outdoor nonpublic fueling: This section has two subsections. Section 10.5.3.3.1 requires that outdoor, nonpublic fuelling installations meet the requirements of the Code that apply to outdoor public fuelling, and Section 10.5.3.3.2 requires that outdoor, nonpublic gas dispensing equipment for hydrogen-powered industrial trucks be listed or approved for outdoor use, in addition to the requirements of Section 10.5.3.2.1 and either Section 10.5.3.2.2 or Section 10.5.3.2.3 [43].
  - Section 10.5.3.4 – Indoor nonpublic fueling: This section sets out prescriptive requirements for indoor fuel dispensing to nonpublic users. These requirements address deflagration venting; construction of rooms for dispensing within or attached to other buildings; exhaust ventilation; gas detection system; reactivation of the fuelling system; ignition source control; indoor area construction; gas-dispensing equipment for indoor slow-fill and fast-fill fuelling of hydrogen-powered industrial trucks; electrical area classification for the dispenser, fire alarm system, emergency shutdown device, fuelling protocols, automatic, and manual shutoff valves; shutdown; reactivation of dispenser and gas flow after shutdown; temperature limits; pressure limits; and defuelling [43].

  Section 19.5 requires that maintenance, service, and repairs of hydrogen-powered industrial trucks be performed in facilities that comply with Section 18.5 of the Code [43]. Section 18.5 sets out the ventilation requirements for heavy-duty hydrogen motor vehicle repair garages.
- UL 2267: Sections 6 through 43 address construction, performance, and markings of industrial electric trucks. Sections 6 through 20 set out the general requirements for construction of industrial electric trucks. These include requirements for risk assessment and risk reduction; hydrogen and other fluid-containing parts; over pressure and thermal protection; operating and shut-off valves; filters, pumps, and compressors; electrically operated pressure sensing and controlling devices; ventilation to prevent the build up of flammable gases and vapours; electrostatic discharge; discharges and waste materials; enclosures; electrical system; and control circuits [110]. Section 6 sets out that Type CGH-EE, Type CGH-EX, and Type CGH-ES fuel cell power systems must also comply with the construction requirements of the applicable truck type in accordance with UL 583 [110]. Section 7

requires the manufacturer of the fuel cell power system to conduct a risk assessment and perform risk reduction using the principles and methodology set out in ISO 12100, *Safety of machinery – general principles for design – risk assessment and risk reduction* [110]. This section also references other standards with requirements for risk assessment and lists the types of hazards the manufacturer must address in the risk assessment and risk reduction [110]. Other sections in this part of the Standard specify the characteristics any materials and components must perform to/meet for a rated assembly (i.e., piping, hoses, tubing, fittings, valves, gauges, internal wiring, connections, motors, compressors, switches, lamps) [110].

Sections 21 through 42 set out the requirements for testing the performance of the fuel cell power system in accordance with applicable standards [110]. These sections set out requirements for a system vibration test; system endurance test; external leakage test; dilution test; testing of potential failure modes; temperature tests; continuity test; dielectric voltage-withstand test; limited power circuits; maximum continuous power output check; abnormal operation – electric equipment failures; exposure to wind;[2] enclosure tests (including loading test, impact test, cold impact test, mold stress test); three-quarter inch flame test for thermoplastic materials; marking plate adhesion test; accelerated air-oven aging test and cold temperature exposure (for elastomeric seals, gaskets, and tubing); permeability tests of nonmetallic tubing and piping; tests of electrical output leads (i.e., cold bend test, accelerated aging test, heat shock test); test of the effectiveness of each emergency stop actuator; and motor evaluation tests (i.e., locked rotor and overload) [110].

Section 43 requires that nameplate markings specified in the Standard are to be permanently secured to the fuel cell power system [110]. Section 43.2 sets out that the marking plate is to include an identifier of the organization responsible for the product (e.g., the manufacturer's name, trademark or other descriptive marking), a catalogue number or equivalent, output electrical rating (in nominal system volts, maximum equivalent amperes, and the maximum continuous VA), type of fuel utilized (including service pressure and maximum operating pressure), total fuel container water in litres along with retest date(s) or expiration date (where the fuel container/tank is fixed and not easily viewed), minimum and maximum ambient temperatures, minimum and maximum storage temperatures (if different from ambient), weight of the fuel cell power system (self-contained systems only), centre of gravity of the fuel cell power system (self-contained systems only), an ingress protection (IP)[3] rating (on fuel cells that comply with Sections 17.1 through 17.3 and Section 33.1.1 of the Standard), and the maximum wind speed in miles per hour (for fuel cell power systems intended to be exposed to elevated wind speeds) [110]. Section 43.3 stipulates that all required markings are to be permanent in accordance with UL 969, *Standard for Marking and Labeling Systems* [110].

Sections 43.5 and 43.6 set out requirements for fuel cell power systems intended for field installation and for use with industrial trucks, respectively. The former requires that the system include a marking to indicate that the system is intended for field installation by qualified personnel only; the latter requires that the system be marked to indicate the appropriate type of industrial truck into which it is intended to be installed and that the marking be located where it will be visible after the system is mounted in the industrial truck [110].

Section 43.11 requires that Type CGH-EE, Type CGH-ES, and Type CGH-EX fuel cell power systems be marked with the truck type designation and that the designation be applied in a prominent location to each exposed side of the fuel cell in accordance with UL 583 [110]. Section 43.12 sets out that self-contained fuel cell power systems that (a) can be moved from one truck to another and (b) do not have an early-warning system as per Section 19.5 of the Standard are to be marked with the following (or equivalent): "WARNING: Automatic Disconnect. Sudden loss of power output may result in loss of control or the sudden stopping of the industrial truck this unit is installed in. Do not install in industrial trucks that can become hazardous upon sudden loss of power" [110].

[2] Not required for systems not provided with a wind speed rating.

[3] A measure of how well a device is protected against water and dust.

- ANSI/CAN/UL 583: Sections 7 through 19 address construction requirements for Type E trucks, Sections 20 through 27 address performance specifications, Section 28 addresses marking requirements, and Section 29 addresses service manual instructions. Sections 30 through 36 address construction requirements for Type EE trucks, Section 37 addresses performance specifications, and Section 38 addresses marking requirements. An explanatory note following Section 30.1 makes explicit that a Type EE truck is not to be powered by fuel cells [111]. Sections 57 addresses construction requirements for Type ES trucks, Sections 58 and 59 address performance specifications, and Section 60 addresses marking requirements. An explanatory note following Section 57.1 makes explicit that a Type ES truck is not to be powered by fuel cells [111].
  - Section 13 – Power source compartment or enclosure: This section sets out prescriptive requirements for the support and protection to be provided to the power source of an industrial truck.
  - Section 14 – Industrial truck power sources: Section 14.3.1 sets out that fuel cells must comply with the requirements in UL 2267. It also requires that the fuel cell enclosure or the compartment in which the fuel cell is located comply with Section 13 of the Standard.
  - Section 21 – Temperature test: This section sets out the temperature tests to be performed on materials used in the construction of an industrial truck. Section 21.1.3 sets out that prior to the temperature test, the truck is to be equipped with a fully charged fuel cell of the maximum operating pressure and continuous output power intended to be used with the specific truck.
  - Section 28 – Marking: Section 28.1 requires that each industrial truck be visibly marked with the name or trademark of the manufacturer, the Type designation (Type CGH, Type E or CGH), the catalogue designation or equivalent identification, maximum rated load in kilograms or pounds or both (including type and position of loading), replacement fuse size located on or adjacent to fuseholders, and the grade in percentage the truck is designed to descend [111].
  - In addition, this section requires that trucks designed to utilize fuel cells must also be visibly marked with the fuel cell catalogue number (or equivalent), output electrical rating in nominal system volts, maximum continuous amperes, and the maximum VA, as well as the dimensions or dimensional limits of the fuel cell that may be used. For trucks designed to use both a battery and a fuel cell, the Standard requires both the fuel cell rating and the battery rating (i.e., battery nominal voltage, maximum ampere-hour capacity, the hour rating at which the capacity is determined) [111].
  - This section also requires that the following or equivalent be visibly marked on trucks that do not provide the required battery enclosure: "Use a Type — battery," and that the types of batteries intended for use in the truck be inserted in the blank [111].
  - Section 28.4 sets out that required markings are to be provided on a metal nameplate permanently secured to the truck or on a marking plate that complies with the Marking-Plate-Adhesion Test (which is outlined in Section 27 of the Standard), unless otherwise specified [111].
- SAE J2601/3: Chapters 5 through 9 include requirements relevant to this project [112]. Chapter 5 addresses operating conditions of the vehicle fuel system, vehicle storage systems, fuelling process limits, special requirements of fleet operations, and special requirements for fuelling light-duty road vehicles with hydrogen-powered industrial truck dispensers. The Standard indicates that the fuelling limits in this section are harmonized with those in CSA HPIT 1, Compressed hydrogen powered industrial truck on-board fuel storage and handling components. Chapter 6 details three examples of fuelling methods that meet the requirements in Chapter 5 of the Standard. The three methods are fill to service pressure, fill to target pressure with fixed orifice, and fill to target pressure with variable flow rate. Chapter 7 lists the four components and procedures that all fast-filling hydrogen-powered industrial truck dispensing methods are to include: automatic shut-off valve, integrity validation, initial integrity check, and integrity check during fuelling event. Chapter 8 describes five options specified by manufacturers: communications, temperature feedback from vehicle tank, water removal/dewatering connection, target pressure calculation methods, and accommodating hot and cold soak conditions. Chapter 9 sets out the three tests required to verify the performance of a hydrogen-powered industrial truck dispenser. These tests are to be designed to demonstrate that hydrogen is delivered to the tank within the specified temperature range and that the vehicle does not exceed 100% Stage of Charge.

Based on the review of these standards, 11 amendments and/or explanatory notes are proposed for consideration by the Technical Committee to address hydrogen-powered forklifts in this section of CSA B335 (see Table 2). These include amendments to the provisions on operating environment (i.e., ventilation and noise), lift truck selection criteria, general safety practices (i.e., warning devices and stability), and safe operating procedures (i.e., pre-operation inspection, fuel handling and storage, and changing and charging storage batteries for electric trucks).

Table 2: Proposed Amendments to Clause 4 of CSA B335 for Consideration by the Technical Committee

Section of the Standard	Suggested Amendments/Additions
4.5.1.3 Hazardous locations	This section requires could include an explanatory note indicating that there is currently no requirement in Chapter 9.5 of NFPA 505 that CGH vehicles be marked.
4.5.2.1 Ventilation	This section could be amended to reflect that proper and adequate ventilation is required in enclosed areas where hydrogen-powered forklifts are used to prevent the build up of any hydrogen released from the lift truck.
4.5.2.2 Ventilation	The explanatory note following this section could be amended to reflect that hydrogen releases can deplete oxygen within enclosed spaces and can create an explosion hazard.
4.5.4 Noise	This section could be amended or an explanatory note could be added to reflect that fuel cell electric vehicles are much quieter than conventional forklifts. Users within the facility should be trained to recognize an approaching CGH-powered forklift.
4.6.1 Lift truck selection criteria – General	This section could be amended to add hydrogen-powered vehicles to the prohibition on the use of lift trucks powered by gasoline, liquefied petroleum gas, or diesel where explosive concentrations of flammable gases or vapours might be present or in areas where exhaust gases might accumulate.
4.8.5.2 Warning devices	This section could be amended to include an explanatory note to emphasize that because fuel cell electric vehicles are extremely quiet, additional warning devices may be needed to make others aware of the fuel cell electric vehicles operating in the facility.
4.8.6.3 Stability	This section could be amended or an explanatory note added to clarify that when battery electric forklifts are converted to fuel cell forklifts, the replacement parts may be of differing weight or weight placement, which could change or compromise the forklift's centre of gravity and reduce the load capacity outside of the vehicle's marked parameters.
4.9.1 Safe operating procedures – preoperation inspection	This section could be amended to include an explanatory note that the pre-operation inspection of a hydrogen-powered forklift should include a process for detecting hydrogen releases. See note below on suggested amendment of Annex A.
4.9.13.2 Fuel handling and storage	This section could be amended to address the storage and handling of hydrogen gas fuel. The amended section should note that the storage and handling of hydrogen shall comply with the authority having jurisdiction and, in the absence of such requirements, shall be in accordance with NFPA 2:2024. An explanatory note could point the reader to the relevant chapters in NFPA 2.
4.9.13.3 Refuelling a fixed LP gas cylinder	This section could be amended to include refuelling of hydrogen-powered forklifts or a new section could be added to provide guidance for refuelling hydrogen with compressed hydrogen gas. The amended or new section should reference both NFPA 505 and NFPA 2.
4.9.14 Changing and charging storage batteries for electric trucks	This section could be amended or another section could be added to include specific language about hydrogen fuel cell batteries. It may be helpful to add an explanatory note that refers the user to requirements in Chapter 9.4 of NFPA 505.

7.2.4 Operator Training Requirements and Qualifications of the Lift Truck Trainer

Of the six standards reviewed for this project, only UL 2267 includes training requirements for operators of hydrogen-powered forklifts that are not addressed in CSA B335.

- UL 2267: Sections 44 through 47 require that a fuel cell power system is to be provided with an instruction manual and set out the requirements for maintenance instructions, operating instructions, and installation instructions [110]. Operating instructions are to include instructions for starting up and shutting down the fuel cell power system, proper refuelling of the fuel cell power system (including a warning to not drive or move the truck with the refuelling hose or interface cable connected), information on the need for adequate process and ventilation air, and an explanation of any warning signals provided with the truck [110]. Section 46.1(e) requires that this information is to include the following statement: "This fuel cell power system uses oxygen from the area in which it is being used. It should not be used in a confined space or unusually tight construction unless provisions are provided for adequate process and ventilation air" [110]. This subsection suggests that the instructions should include an example of how to determine the volume of a typical area. Explanatory notes following this subsection reference the definition of a confined space in NFPA 54, *National Fuel Gas Code,* and describe the conditions considered to be "unusually tight construction" [110].

Based on the review of all six standards, 10 amendments and/or explanatory notes are recommended for consideration to address hydrogen-powered forklifts in the sections of CSA B335 that address operator training and trainer qualifications (see Table 3). Nine amendments are recommended for consideration to the operator training requirements: lift truck features and safety equipment; stability; pre-operational inspection; workplace-specific hazards; procedures for shutdown and leaving the operator's position (i.e., shutdown); refuelling and recharging (i.e., general requirements, refuelling other hydrocarbons, and battery recharging and exchange); and evaluations (i.e., knowledge verification). One amendment to Clause 7.3 (Knowledge) in this section of the Standard that addresses lift truck trainer qualifications is recommended for consideration.

7.2.5 Maintenance and Repair Practices and Competence of Maintenance Technicians

Of the six standards reviewed for this project, three include requirements for maintenance and repair, as well as maintenance technician competency that are not addressed in CSA B335.

- NFPA 505: Chapters 7 and 8 address the conversion and maintenance of industrial powered trucks. Chapter 7 sets out the requirements for converting power-operated industrial trucks for non-hazardous (i.e., ordinary) locations to an alternative fuel and/or power system [109]. Section 7.1.4 requires that a conversion that impacts the truck's stability or centre of gravity be done in accordance with the requirements of ANSI/ITSDF B56.1 or the original manufacturer [109]. Section 7.2.2 sets out that conversion kits for converting an electrically powered truck (i.e., Type E) to a fuel cell–powered electric industrial truck must comply with the applicable requirements of UL 583 and UL 2267. This chapter of the Standard also sets out that conversion kits must (a) be approved by a testing laboratory and (b) include step-by-step installation instructions, all parts necessary to complete the installation, and a durable corrosion-resistant plate (indicating the type designation of the converted truck) for permanent mounting adjacent to the manufacturer's nameplate [109]. Where a truck is converted to CGH and a removable CGH module is used, the Standard requires that a durable corrosion-resistant nameplate also be attached to the CGH module that complies with the marking requirements of UL 2267 [109]. Chapter 8 sets out requirements for maintenance of power-operated industrial trucks, which include hydrogen-powered forklifts [109]. Section 8.2 requires that repairs to the fuel and ignition systems of industrial trucks that involve fire hazards be conducted only in designated repair locations, and that repairs to the electrical system of battery-powered trucks be performed only after the battery has been disconnected.

Table 3: Proposed Amendments to Clauses 6 and 7 of CSA B335 for Consideration by the Technical Committee

Section of the Standard	Suggested Amendments/Additions
6 Operator training requirements	
6.5 Lift truck features and safety equipment	This section could be amended to include training on the powertrain of the individual unit(s) the employer has in service, the hazards associated with them, the safety precautions specific to that type of unit, and the specific engineering controls within the facility to address hazards. Alternatively, an explanatory note could be added to clarify that subsections (a) and (b) should include this information.
6.6 Stability	This section could include an explanatory note that highlights how the conversion of an electrically powered truck to a fuel cell powered–electric industrial truck may impact stability and the lift truck's centre of gravity.
6.8 Preoperational inspection	This section could include an explanatory note incorporating guidance from Chapter 9 of NFPA 505 that a match or open flame shall not be used to check for leaks in compressed gas hydrogen fuel systems.
6.16 Workplace-specific hazards	This section could be amended or an explanatory note could be added to include that the trainees on hydrogen-powered forklifts shall be instructed on the accumulation of hydrogen in enclosed spaces and the possibility of hydrogen leaks during refuelling and battery changes.
6.17.1 Shutdown	This section could be amended to incorporate guidance from Chapter 9 of NFPA 505 that compressed hydrogen gas fuel cell system–powered lift trucks shall not be parked near sources of heat or open flames or similar sources of ignition.
6.18.1 Refuelling/ recharging – General	This section could be amended to include the trainee being instructed on workplace-specific elements intended to protect the area or the facility from the flammability of hydrogen (e.g., gas sensors, infrared flame detection, ventilation).
6.18.3 Refuelling other hydrocarbons (diesel, gasoline, natural gas, and propane)	This section could be amended to reflect that hydrogen is a fuel source.
6.18.4 Battery recharging/ exchange	This section could include an explanatory note that, in accordance with NFPA 505, only trained and authorized personnel are to change replaceable fuel cell system modules in hydrogen-powered forklifts (i.e., Type CGH trucks) or replace batteries in electric forklifts (i.e., Type E trucks) with fuel cell system modules.
6.20.2 Knowledge verification	This section could be amended to include that all trainees shall be evaluated on the hazards of hydrogen-powered forklifts, as well as hydrogen-specific elements in the preoperational inspection.
7 Qualifications of the lift truck trainer	
7.3 Knowledge	Subsections (g) and (h) of this section could be amended to incorporate hydrogen fuel cell systems.

- NFPA 2: Chapters 18 and 19 address repair garages and hydrogen-powered industrial trucks, respectively. Chapter 18 applies to buildings and structures used for service and repair operations associated with self-propelled, GH_2-powered vehicles. Section 18.2.2 sets out that the storage, use, and handling of GH_2 in any quantity must comply with Chapters 1 and 4, as well as the applicable requirements of Chapters 5 through 7; and Section 18.2.3 requires that dispensing of GH_2 comply with Chapter 10 [43]. The requirements in this chapter distinguish between major repair garages and minor repair garages for hydrogen vehicles.

  Section 18.6 sets out the requirements for hydrogen-powered industrial truck repair garages. Specifically, Section 18.6.1.1 requires that minor repair garages for hydrogen-powered industrial trucks comply with Chapter 8 of NFPA 505, and Section 18.6.1.3 allows for the replacement of cell stacks in fuel cell power systems in minor repair garages for hydrogen-powered industrial trucks [43]. For major repair garages, Section 18.6.2.1.1 requires that major repair garages that service only hydrogen-powered industrial trucks comply with sections 18.6.2.1 through 18.6.2.4 of the Code. Section 18.6.2.2 clarifies that repairs of the hydrogen fuel system (which includes piping and components up to the fuel cell stack) must comply with sections 18.6.2.2.1 through 18.6.2.2.2 [43]. The former requires that all automatic fuel valves in the hydrogen-powered industrial truck to be serviced be closed before service is initiated, and that measures be taken to ensure they remain closed during the servicing; the latter requires that all manual valves in the hydrogen-powered industrial truck to be serviced be closed before service is initiated [43]. Section 18.6.2.3 requires that all hydrogen fuel storage containers (which includes tanks, vessels, cylinders, etc.) in the hydrogen-powered industrial truck to be serviced be defuelled before service is initiated [43]. Section 18.6.2.4 requires that major repair garages servicing both hydrogen-powered industrial trucks and powered industrial trucks using other fuels comply with the requirements of Section 18.6 of the Code and with NFPA 30A, *Code for Motor Fuel Dispensing Facilities and Repair Garages* [43].

  Chapter 19 (Section 19.5) requires that maintenance, service, and repairs of hydrogen-powered industrial trucks be performed in facilities that comply with Section 18.5 of the Code [43]. Section 18.5 sets out the ventilation requirements for heavy-duty hydrogen motor vehicle repair garages.

- UL 2267: Sections 44 through 47 require that a fuel cell power system is to be provided with an instruction manual and set out the requirements for maintenance instructions, operating instructions, and installation instructions [110]. Maintenance instructions for a fuel cell system with replaceable batteries are to include instructions for replacing the battery, as well as the type and rating of the batteries, while those for a fuel cell system with replaceable fuses are to include instructions for replacing the fuses, as well as the fuse type, voltage, and current rating [110]. In addition, the Standard requires instructions on the need to prevent blockage of ventilation and exhaust openings, for basic inspection and maintenance (i.e., filter cleaning, and replacement and lubrication of parts), the source for replacement parts, and the necessity and frequency of period examination and inspection by qualified personnel (e.g., inspection of gas detectors, pressure switches, other safety critical components that require calibration) [110].

  Installation instructions are to be provided for the proper installation of a fuel cell power system and are to include "spacing requirements, location of ventilation and exhaust openings, securement, electrical connections and fuel connections" [110]. The Standard also requires instructions to be provided and the system to be labelled where a hazard may be present through system orientation or positioning; instructions for the proper installation of the storage system if storage tanks are provided (these are to include instructions for the connection of the fuel lines to the fuel cell power system); instructions for a field-installed fuel cell power system to include a statement that the system is intended for installation by qualified personnel only; and installation instructions for self-contained fuel cell systems marked in accordance with Section 43.12 to indicate that the systems are not to be installed on trucks unless an assessment has determined that the truck will not present a hazard upon loss of power [110]. Section 19.5 (early warning system) is to be consulted before the system is installed.

Based on the review of all six standards, seven amendments to Clauses 8 and 9 of CSA B335 (see Table 4) are recommended for consideration. Six are amendments to the general maintenance requirements, the provisions on precautions before starting inspections, and additional maintenance and repair precautions. One amendment to the general competency requirement for maintenance technicians is recommended for consideration.

7.2.6 Annexes

Based on the review of all six standards recommended for consideration are amendments to Annex A, Annex D, and Annex F (see Table 5). These include the development of sample checklists to incorporate applicable elements listed in NFPA 505 and NFPA 2, as well as information on fuel charging requirements and refuelling procedures.

Table 4: Proposed Amendments to Clauses 8 and 9 of CSA B335 for Consideration by the Technical Committee

Section of the Standard	Suggested Amendments/Additions
8 Maintenance and repair practices	
8.1.3 General	This section could be amended to include that samples of generic inspection checklists for hydrogen-powered lift trucks are provided in Annex A.
8.3.2 Precautions before starting inspections	This section could be amended to include the specific precautions to be taken for hydrogen power trains.
8.3.4 Precautions before starting inspections	This section could be amended to include that a match or open flame shall not be used to check for leaks in compressed gas hydrogen fuel systems.
8.3.5 Precautions before starting inspections	This section may require amendment or an explanatory note about the need to properly and adequately ventilate the space to ensure there is no build-up of hydrogen. An explanatory note should be included that references the relevant requirements on repair garages in NFPA 2.
8.5.2 Additional maintenance and repair precautions	This section could be amended to include that special consideration shall be given in the case of a leak in the fuel and the fuel cell system. An explanatory note illustrating the hazards of a hydrogen leak may also be helpful.
8.5.11 Additional maintenance and repair precautions	This section could be amended to include that replacement fuel cells for hydrogen-powered lift trucks shall be of the same service weight that falls within the maximum/minimum range specified by the truck manufacturer.
9 Competence of maintenance technicians	
9.1 Competence of maintenance technicians – General	This section could include an explanatory note that only trained and authorized personnel shall change fuel cell system modules on hydrogen-powered forklifts.

Table 5: Proposed Amendments to Annexes A, D, and F of CSA B335 for Consideration by the Technical Committee

Section of the Standard	Suggested Amendments/Additions
Annex A **Sample inspection checklists**	A sample preoperation inspection checklist and a service/inspection report for technicians that are applicable to hydrogen-powered lift trucks could be developed for inclusion in this Annex. These checklists should incorporate elements listed in relevant NFPA standards.
Annex D **Batteries and battery charging**	This Annex could be amended to include information on fuel cells and charging requirements for hydrogen-powered lift trucks, as well as the unique requirements for hydrogen refuelling stations. Relevant elements in NFPA 505, NFPA 2, and SAE J2601 should be incorporated.
Annex F **Example operator evaluation form**	Table F.1 in this Annex could be amended to include refuelling procedures for hydrogen-powered forklifts. These procedures should incorporate or be informed by relevant procedures in NFPA 505 and NFPA 2.

8 Key Gaps, Challenges, and Opportunities

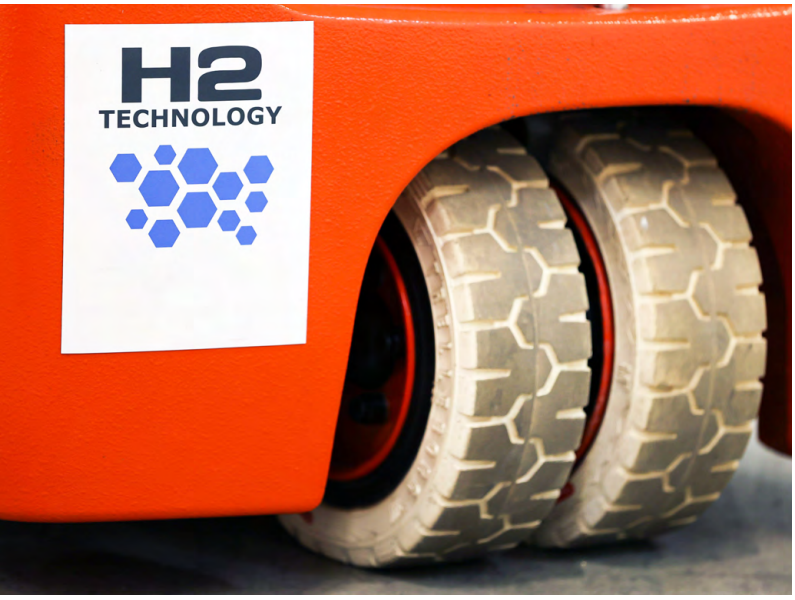
8.1 Key Gaps and Challenges

8.1.1 Knowledge and Research Gaps

The literature review and the key informant interviews confirmed that although there is a large body of literature on both hydrogen and general forklift safety, there are research and knowledge gaps in our understanding of hydrogen-powered forklifts. As stated in Section 4.3 of this report, there is at present very limited literature on the *specific* hazards and risks introduced by the hydrogen fuel cell power system and its interaction with the hazards that are already present on a forklift. For example, several key informants raised the issue of forklifts running into things in the workplace and questioned whether such impacts are more likely to result in damage to the fuel cell and subsequent hydrogen leaks. Several of the reviewed research articles recommended that further research be undertaken to explore and credibly assess worst-case consequences in realistic congested enclosures. At present, there is little to no research on the hazards of forklifts powered by hydrogen ICEs.

Only one peer-reviewed study was found that assessed the potential harm to drivers of fuel cell forklifts converted from repurposed electric forklifts due to hydrogen being released from the compressed gas storage and delivery system. The authors of this quantitative risk assessment highlight the lack of hydrogen-specific databases as a critical gap, noting that better and publicly accessible data on incidents in fuel cell forklifts would not only identify "major operational hazards and the most likely components to fail," but would also contribute to more robust quantitative risk assessments and yield risk estimates "closer to reality" [20]. In addition, the authors recommend that further research be done on analyzing leakage, as well as frequency and probability of failure of a proton-exchange membrane fuel cell, of specific designs of hydrogen-powered forklifts [20]. The lack of quantitative data was consistently identified as a gap across the studies reviewed.

Key informants also observed that there were some important knowledge gaps. For example, more needs to be known about what the most likely leak scenarios are and which of those are the most hazardous. A research study could identify where leaks are most likely to occur, quantify the risk, and identify solutions to remedy the risk. Hydrogen refuelling and repurposing of electric forklifts with fuel cells were also identified as areas for further study. Although some key informants thought that hydrogen leaks would be unlikely during refuelling, others wouldn't dismiss refuelling as a potential leak scenario. They added that it would be worthwhile to undertake additional research to quantify the risk of hydrogen exposure during indoor refuelling because there is little to no research examining this issue. As to



"There is at present very limited literature on the *specific* hazards and risks introduced by the hydrogen fuel cell power system and its interaction with the hazards that are already present on a forklift."

repurposing, further research could shed some light on whether the replacement of an electric battery with a fuel cell introduces new hazards by changing the geometry or stability of the forklift. This knowledge gap was also identified in the literature.

8.1.2 Gaps in the Policy Landscape

At present, none of the jurisdictions scanned in Canada or internationally have regulatory requirements that address the specific hazards of hydrogen-powered forklifts. Despite the presence of a relatively robust OHS regulatory framework in Canada, the environmental scan identified a number of gaps and inconsistencies in how forklifts are regulated in general. These differences are found in the terms used to refer to forklifts, how the terms are defined, and even in the specifics of some of the regulatory requirements. Across the 14 Canadian jurisdictions, there were inconsistencies in the general duties regarding the design, operation, and maintenance of forklifts; operator training and competency requirements; inspection and monitoring requirements; maintenance requirements; and whether CSA B335 is incorporated by reference in regulations. Only five of fourteen Canadian jurisdictions have incorporated by reference CSA B335 into their regulations. In addition, the edition of the standard referenced varies considerably. Nova Scotia and British Columbia reference editions published in the last 10 years, while Manitoba and Quebec reference editions published 20 years or more ago. Newfoundland and Labrador makes an ambulatory reference to CSA B335.

Six voluntary standards were reviewed as part of this project. Except for SAE J2601/3, hydrogen-powered forklifts are not the focus of the standards. However, they all include some requirements that apply to the design, operation, and/or maintenance of fuel cell forklifts. Other than ANSI/ITSDF B56.1, none of the six voluntary standards are incorporated by reference in the forklift regulations across Canada. The six standards cross-reference each other in a number of places; this could create challenges for users having to track down multiple standards to comply with the requirements of one standard.

8.2 Opportunities for Standardization

The rising number of warehouses, the increased prevalence of forklifts powered by alternative fuel sources such as hydrogen, and the fact that CSA B335 does not address hydrogen-powered forklifts were the key motivators for this research. In addition to reviewing the current state of knowledge on the hazards of fuel cell system–powered forklifts and the current regulatory landscape, this project reviewed CSA B335 to identify areas where gaps existed and where there might be opportunities for improvement.

Key informants agreed that there was no apparent need for a stand-alone standard on hydrogen-powered forklifts and that amendment of CSA B335, and perhaps the creation of an informative annex, might address the gaps in the current Standard. However, some key informants commented that it

could be useful to standardize fuelling nozzles and connections. Another interviewee recommended for consideration standardization of maintenance protocols and inspection requirements to address and remedy incipient leaks. This could include, for example, requirements for daily inspection, the kind of equipment used to detect leaks, and the need for a handheld detection device at the refuelling station. This supported one of the recommendations made by the authors of the quantitative risk assessment published in 2023, namely that "particular attention and efforts should be paid to the inspection, monitoring, and maintenance of the filter and pressure relief devices in a hydrogen forklift's storage and delivery system" [20].

Based on the review of the six voluntary standards, several areas for improvement were identified in CSA B335. These include the addition of reference publications, terms, and definitions, as well as amendments to the general requirements, the operator training requirements, qualifications of the lift truck trainer, maintenance and repair practices, competence of maintenance technicians, and three of the informative annexes. Given the potential consequences of a major hydrogen release, it may also be useful for the Technical Committee in charge of the Standard to develop and include an additional informative annex that discusses the properties and hazards of hydrogen. Annex D of NFPA 2 may provide a useful starting point.

9 Conclusions

The rise of e-commerce has led to a rising number of warehouses in Canada, which in turn has led to an increased prevalence of forklifts. Hydrogen as a fuel source provides consistent power levels, fast refuelling, potentially clean/sustainable energy production, and no on-site carbon emissions. Hydrogen is fast becoming considered a viable alternative energy source for forklifts. Hydrogen-powered forklifts are already in use in Canada and the US, with the North American market for these forklifts expected to grow in the next decade. Despite this, CSA B335, *Safety standard for lift trucks,* does not address hydrogen-powered forklifts. The objective of this research was to gain a better understanding of the needs, gaps, and opportunities for hydrogen-powered forklifts, as well as to provide recommendations for consideration to the CSA Technical Committee in charge of CSA B335 about how the Standard could be expanded to address and reflect the needs of these forklifts.

The findings herein reveal that while much is known about the hazards of hydrogen and general forklift safety, the specific hazards of hydrogen-powered forklifts are understudied. Among the few studies into hydrogen risks, a higher potential for fire and explosions are the most pressing hazards. Hydrogen-specific quantitative research, data, and databases are needed to understand the frequency and probability of failure of a proton-exchange membrane fuel cell, the impact of different warehouse shelving configurations on the dispersion of hydrogen leaks, the most effective ventilation configurations, likely leak scenarios (including during refuelling), the risk of hydrogen exposure during indoor refuelling, and whether the replacement of an electric battery with a fuel cell introduces new hazards.

Despite the presence of a relatively robust OHS regulatory framework in Canada, the environmental scan identified several gaps and inconsistencies in the forklift regulations across the country. At present, no jurisdiction in Canada has regulations that address hydrogen-powered forklifts. There are, however, a number of voluntary standards that include requirements applicable to fuel cell forklifts. These requirements informed recommendations for consideration by the Technical Committee responsible for CSA B335 to address hydrogen as a fuel source for forklifts, which was suggested by key informants to be potentially more useful than a stand-alone standard on hydrogen-powered forklifts.

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Appendix A – Cross-Jurisdictional Comparison of Relevant Regulations

A.1 Relevant Forklift-Related Terms Used in Canadian OHS Regulations

Table A.1-1: Cross-Canada Comparison of Terms Used to Refer to Forklifts

	BC	AB	SK	MB	ON	QC	NL	NS	NB	PE	YT	NT	NU	CA
Forklift														
A self-propelled machine that has a power-operated upright, angled, or telescoping lifting device that can raise and lower a load for the purpose of transporting or stacking			X									X	X	
Powered Lift Truck														
Powered mobile equipment that is designed to allow the operator to lift, carry, and unload a load; within a class of trucks to which the code of practice referred to in the regulation applies				X										
A mobile, power-propelled, self-loading truck equipped with a load carriage and attachments for lifting, transporting, and stacking material					X									
Lift Truck														
A lift truck as defined in the latest version of ANSI standard ANSI/ITSDF B56.1, “Safety Standard for Low Lift and High Lift Trucks								X						
Mobile Equipment														
A prime mover, or a prime mover with a towed component, which towed component moves relative to the ground, or has a rider, for its work function	X													
A wheeled or tracked vehicle that is engine or motor powered, together with attached or towed equipment, but does not include a vehicle operated on fixed rails or tracks							X				X			
Powered Mobile Equipment														
Self-propelled machinery designed to carry, push, pull, dig, compact, lift, stack, tier, or move materials or to provide a working platform for workers, and includes trucks										X				
A self-propelled machine or combination of machines, including a prime mover or a motor vehicle, designed to manipulate or move material or to provide a powered aerial device for workers		X												
A self-propelled machine or combination of machines, such as a prime mover, that is designed to manipulate or move materials or to provide a work platform for a worker			X									X	X	
A self-propelled machine or combination of machines, including a prime mover or a vehicle, used to manipulate or move material, move workers, or provide a powered aerial device for workers				X										

	BC	AB	SK	MB	ON	QC	NL	NS	NB	PE	YT	NT	NU	CA
Prime Mover														
A self-propelled ground machine, with wheels or endless tracks, designed or used for work, including any attachment, but not including an excluded ground machine	X[1]													
An initial source of motive power					X									
Lifting Device														
A device that is used to raise or lower any material or object, and includes its rails and other supports but does not include a device to which Ontario Regulation 209/01 (Elevating Devices), made under the *Technical Standards and Safety Act, 2000,* applies					X									
A device that is used to raise or lower material or an object, but does not include a crane or a hoist			X									X	X	
Hoisting Apparatus														
Includes cranes, travelling cranes, gantries, winches, blocks, lift trucks, aerial basket lifting devices, work platform lifts, screw-type jacks, rack-type jacks, and other similar apparatus, but does not include elevators and dumbwaiters						X								
Includes mobile cranes, tower cranes, electric overhead travelling cranes, vehicle hoists, winches, and other similar equipment, but does not include elevators, dumbwaiters, or mine hoists										X				
Materials Handling Equipment														
Equipment, including its supporting structures, auxiliary equipment and rigging devices, used to transport, lift, move or position persons, materials, goods or things and includes mobile equipment used to lift, hoist or position persons, but does not include an elevating device that is permanently installed in a building														X

Notes:

[1] The BC regulations identify lift trucks as a specific type of prime mover.

A.2 Cross-Canada Comparison of Relevant Forklift Regulations

Table A.2-1: Lift Truck Standards Referenced in Canadian OHS Regulations

	BC	AB	SK	MB	ON	QC	NL	NS	NB	PE	YT	NT	NU	CA
Design, fabrication, use, maintenance, and repair of a lift truck must meet one of the following standards														
CAN/CSA B335-15	X													
CAN/CSA B335-04				X[2]										
CSA B335.1-1977						X[3]								
CSA B335							X[5]							
CSA B335 (latest version)								X						
ANSI/ITSDF B56.1a-2018	X[1]													
ANSI/ITSDF B56.1 (latest version)								X						
ANSI/ASME B56.1				X[2]										
ANSI/ASME B56.1-1993						X[4]								
ANSI/ASME B56.1-2000											X			
Operator training must meet requirements of one of the following standards														
CSA B335-15, clause 6	X													
CSA B335-04											X			
other standards acceptable to the Board											X			

Notes:

[1] Must meet version of standard referenced in regulation or the version of the applicable standard that applied on the date of lift truck manufacture.

[2] This standard is referenced in the Code of Practice for the Safe Operation of Powered Lift Trucks, which was published in 2006. The Code of Practice is referenced in the *Workplace Safety and Health Regulation*.

[3] Under the Quebec regulations, lift trucks built before August 2, 2001, must comply with this standard.

[4] Under the Quebec regulations, lift trucks built on or after August 2, 2001, must comply with this standard.

[5] The regulation in Newfoundland and Labrador states that the "design, fabrication, use, inspection, and maintenance" of mobile equipment must meet the referenced standard.

Table A.2-2: Cross-Canada Comparison of Training and Competency Requirements in the OHS Regulations

	BC	AB	SK	MB	ON	QC	NL	NS	NB	PE	YT	NT	NU	CA
General requirements for operator training and competency														
Lifting device only to be operated by a competent person or a worker being instructed by a competent person					X[1]									
Forklift truck to be operated only by an operator who has undergone training and practical training under the supervision of an instructor						X[2]								
Mobile equipment to be operated only by a person who (a) has received adequate instruction and has demonstrated to a supervisor or instructor they are a competent equipment operator, (b) has been authorized to operate it, and (c) is familiar with the operating instructions for the particular equipment before attempting to operate							X[3]							
Minimum age														
Every operator of a forklift truck must be at least 16 years of age						X								
Obligations imposed on employers														
Every employer or contractor shall ensure that only trained operators are required or permitted to operate powered mobile equipment			X[4]											
Employer or contractor shall ensure that required training is provided by competent persons			X[4]											
Employer or contractor must designate a worker to operate the lifting device and ensure that the designated operator is trained in the operation of the device			X											
Employer or contractor must ensure that only a worker who is a designated operator operates the lifting device			X											
No employer shall require or permit a worker to operate a powered lift truck unless the employer has issued a certificate to the worker				X										
No employer shall issue a certificate to a worker to operate a powered lift truck unless the employer has first ensured the worker (a) has received instruction, training, and testing in the lift truck operation in accordance with the approved code of practice; (b) is familiar with the operating procedures of the lift truck to be operated; and (c) has demonstrated competency in the operation of the lift truck to be operated in accordance with the approved code of practice				X[5]										
Employer must ensure that every supervisor and operator of a lift truck has been provided with necessary information, instruction, training, supervision, facilities, and equipment required for safe operation in accordance with the referenced standards								X						
Employer must ensure that lift truck is only operated by a competent person								X	X	X				
Employer must ensure that lifting device is only operated by a competent person authorized by employer to operate the equipment		X												
Employer must designate a worker to operate the lifting device and ensure that the designated operator is trained in the operation of the device												X	X	

	BC	AB	SK	MB	ON	QC	NL	NS	NB	PE	YT	NT	NU	CA
Obligations imposed on workers														
Employer must ensure that only a worker who is a designated operator operates the lifting device												X	X	
Employer must ensure that every operator of motorized materials-handling equipment has been instructed and trained in the procedures to be followed for its inspection, fuelling, and safe and proper use, in accordance with any instructions provided by the manufacturer and taking into account the conditions of the workplace in which the equipment is operated														X[6]
Employer must ensure that every operator of manual materials-handling equipment receives on-the-job-training by a qualified person on the procedures to be followed for its inspection and safe and proper use, in accordance with any instructions provided by the manufacturer and taking into account the conditions of the workplace in which the equipment is operated and the operator's physical abilities														X
No employer shall require a worker to operate motorized or manual materials-handling equipment unless the worker is an operator and, where the laws of the province in which the equipment is operated require an operator's licence, possesses an operator's licence issued by any province														X
Obligations imposed on supervisors														
Supervisor shall not knowingly operate, or permit a worker to operate, mobile equipment that is or could create an undue hazard to the health and safety of a person or is in violation of regulations							X							
Supervisor shall ensure that they do not knowingly operate, or permit a worker to operate, mobile equipment that is or could create an undue hazard to the health and safety of a person or is in violation of regulations											X			
Supervisor shall ensure they take appropriate action to correct any reported defects or unsafe situations before the mobile equipment is returned to service											X			
Obligations imposed on workers														
Worker must not operate powered mobile equipment unless the worker (a) is trained to safely operate the equipment, (b) has demonstrated competency in operating the equipment to a competent worker designated by the employer, (c) is familiar with the equipment's operating instructions, and (d) is authorized by the employer to operate the equipment		X												
A worker in training is permitted to operate the equipment under the direct supervision of a competent worker designated by the employer		X												
Worker shall not operate mobile equipment unless they (a) have received adequate instruction and have demonstrated to a supervisor or instructor they are a competent equipment operator, (b) have been authorized to operate the equipment, (c) are familiar with the operating instructions for the particular equipment before they attempt to operate it							X							
Workers who are trainees permitted to operate mobile equipment if they are under the supervision of a qualified instructor or supervisor as authorized by employer							X							

	BC	AB	SK	MB	ON	QC	NL	NS	NB	PE	YT	NT	NU	CA
Obligations imposed on workers														
Workers shall only operate mobile equipment if they have (a) received adequate training in the safe use and operation of the equipment, (b) demonstrated competency in operating the equipment to a supervisor or a qualified person, (c) familiarity with the operating instructions for the mobile equipment, and (d) been authorized by a supervisor to operate the equipment											X			
Workers who are trainees shall only operate mobile equipment if they are under the direct supervision of a supervisor or a qualified person											X			
Worker shall not operate a lifting device unless they are a designated operator and have been trained in the operation of the device			X									X	X	
Records														
Employer who issues certificate to a worker must (a) establish and implement an evaluation system to ensure worker maintains competency, (b) maintain a record of training worker receives in lift truck operation, and (c) produce a copy of the certificate and record upon request				X[7]										
Employer to keep a written record, in respect of an operator, of any instruction or training provided for as long as the operator remains in the employer's employment														X

Notes:

1 Ontario published a Guideline for the safe operation and maintenance of powered lift trucks in 2023. This guideline sets out competency requirements for both operators and maintenance technicians.

2 The Quebec regulations stipulate that training is to include "basic notions concerning fork lift trucks, the work environment and how it affects the operation of a fork lift truck, the operation of a fork lift truck, and safety rules and measures"; and practical training is to address the "operation of a fork lift truck such as starting, moving and stopping, handling loads and any other manoeuvre necessary to operate a fork lift truck." In addition, the practical training "must begin, if possible, outside of the area used for current operations and then be completed in the regular work area." Both types of training must include requirements concerning "the work environment, its specific conditions and the type of fork lift truck to be operated."

3 In Newfoundland and Labrador, mobile equipment may be operated by a trainee under the supervision of a qualified instructor or supervisor as authorized by employer.

4 In Saskatchewan, this does not apply to persons directly engaged in a farming or ranching operation.

5 Manitoba published a Code of Practice for the Safe Operation of Powered Lift Trucks in 2006 that is referenced in *The Workplace Safety and Health Regulation.* The Code of Practice sets out how an employer is to establish the competence of operators, as well as the knowledge and skills an operator must possess.

6 Does not apply to an employer with respect to an operator who is being instructed and trained in use of equipment under the direct supervision of a qualified person.

7 The Manitoba Code of Practice requires retraining "at intervals not exceeding three years" and sets out examples of when a refresher course must be given to operators that include when "conditions in the workplace change that may affect the safe operation of the powered lift truck."

Table A.2-3: Cross-Canada Comparison of Pre-use and Regular Inspection Requirements

	BC	AB	SK	MB	ON	QC	NL	NS	NB	PE	YT	NT	NU	CA
Pre-use and routine inspection														
Operator must inspect and report any unsafe, or potentially unsafe, defects to supervisor or employer before mobile equipment is first operated on a shift	X													
Operator must continuously monitor performance during operation and report any unsafe, or potentially unsafe, defects to supervisor or employer	X													
Operator must complete a visual inspection of the equipment and the surrounding area before operating the powered mobile equipment to ensure equipment is in safe operating condition and that no worker, including the operator, is endangered when the equipment is started up		X												
A person must not start powered mobile equipment if the visual inspection is not completed		X												
Operator of powered mobile equipment must report to the employer any conditions affecting the safe operation of the equipment		X												
Employer or contractor shall ensure that worker makes a complete visual inspection of the equipment and surrounding area to ensure that no worker, including the operator, is endangered by the start-up of the equipment			X											
Worker not permitted to start powered mobile equipment until the visual inspection is completed			X											
Employer must ensure that the operator completes a visual inspection of the equipment and surrounding area to ensure that no worker, including the operator, is endangered by the start-up of the equipment				X										
Hoisting device must be inspected before it is used for the first time						X								
Hoisting device must be inspected and maintained in accordance with manufacturer's instructions or standards offering equivalent safety						X								
Self-propelled vehicle to be inspected and maintained in accordance with the manufacturer's instructions or standards offering equivalent safety						X								
Operator must (a) inspect mobile equipment before start of operation on shift and after where required and (b) immediately report defects or other conditions affecting safe operation to supervisor or employer							X							
Inspection, repair, maintenance, and modification to be carried out in accordance with manufacturer's instructions or, in the absence of instructions, as approved by a registered professional engineer							X							
Employer must ensure that industrial lift truck is inspected daily and maintained in good operating condition									X					

	BC	AB	SK	MB	ON	QC	NL	NS	NB	PE	YT	NT	NU	CA
Pre-use and routine inspection														
Operator must inspect powered mobile equipment before start of operation of each shift to ensure equipment is in safe operating condition										X				
Mobile equipment to be regularly inspected											X			
Operator must (a) inspect mobile equipment before start of operation on shift and thereafter as required and (b) report defects and conditions affecting safe operation to supervisor as they are noticed											X			
Operator must ensure they inspect the mobile equipment in accordance with instructions from employer and the manufacturer before starting it											X			
Inspection and repair by competent person														
Employer must ensure that equipment is inspected by a competent worker for defects and conditions that are hazardous or may create a hazard and that the inspection is made in accordance with the manufacturer's specifications		X												
Employer or contractor must ensure that all powered mobile equipment is inspected by a competent person for defects and unsafe conditions as often as necessary to ensure that it is capable of safe operation			X											
Employer or contractor must ensure that where a defect or unsafe condition is identified, immediate steps are taken to protect health and safety of workers at risk until the defect is repaired or the unsafe condition is corrected and repair the defect or correct the unsafe condition as soon as reasonably practicable			X											
Employer, contractor or supplier must ensure that lifting device is inspected by a competent individual to determine whether it is in safe working condition at the start of each work shift before device is used and at regular intervals as recommended by manufacturer			X											
Employer, contractor or supplier must ensure that where a defect or unsafe condition is identified in a lifting device, immediate steps are taken to protect health and safety of workers at risk until the defect is repaired or the unsafe condition is corrected and repair the defect or correct the unsafe condition as soon as reasonably practicable			X											
Employer must ensure that all powered mobile equipment is inspected by a competent person for defects and unsafe conditions as often as necessary to ensure the equipment is in safe operating condition and in accordance with the manufacturer's specifications				X										
Employer must ensure that, where a defect or unsafe condition that is hazardous or that may create a risk to health or safety is identified, the powered mobile equipment is not operated until the defect is repaired or the unsafe condition is corrected				X										
Lifting device must be thoroughly examined by a competent person to determine capability of handling the maximum load as rated prior to being used for first time and thereafter at least once a year					X[1]									

	BC	AB	SK	MB	ON	QC	NL	NS	NB	PE	YT	NT	NU	CA
Pre-use and routine inspection														
Employer must ensure that a competent person thoroughly inspects and repairs an industrial lift truck and any safety devices installed on it before it is first put in use and after any incident that may have damaged some part of it									X					
Employer or supplier must ensure that lifting device is inspected by a competent individual to determine if it is in safe working condition at the start of each work shift before device is used and at regular intervals as recommended by manufacturer's specifications												X	X	
Inspection, testing, and maintenance of motorized or manual materials-handling equipment to be performed by qualified person														X
Record of inspection														
Employer must ensure that record of inspection is kept at the worksite and is readily available to a worker who operates the equipment		X												
Employer or contractor must ensure that a written record of inspections and maintenance carried out on powered mobile equipment is kept at the place of employment and is made readily available to the operator			X											
Employer must ensure that written record of inspections, repairs, and maintenance carried out on powered mobile equipment is kept at the worksite and made readily available to the operator of the equipment				X										
Record of examination must be signed by competent person doing the examination and kept by employer for at least one year or a period long enough to ensure that the two most recent records are kept					X									
Qualified person must make and sign a report of each inspection, test, or maintenance work performed by qualified person														X[2]

Notes:

[1] The Ontario regulations state "thereafter as often as necessary but not less frequently than recommended by the manufacturer and in any case at least once a year." Ontario's Guideline for the safe operation and maintenance of powered lift trucks clarifies the intent of this regulation.

[2] The report must include date of inspection, testing or maintenance performed by qualified person, identify the equipment that was inspected, tested, or maintained, and set out the safety observations of the qualified person.

Table A.2-4: Cross-Canada Comparison of Maintenance Requirements

	BC	AB	SK	MB	ON	QC	NL	NS	NB	PE	YT	NT	NU	CA
Modifications, repairs, additions, and maintenance														
Employer, contractor, owner, or supplier must ensure that powered mobile equipment is constructed, structurally repaired, inspected, tested, maintained and operated in accordance with the manufacturer's specifications or an approved standard			X											
If inspection reveals a condition that might render lifting device unsafe, an employer, contractor, or supplier shall not require or permit the use of the device until any necessary repairs are completed			X											
Any modifications, repairs, and additions that affect capacity or safe operation of the lift truck must be performed with the written approval of the manufacturer or a professional engineer qualified in that work				X										
Vehicle to be maintained in accordance with the manufacturer's instructions or standards offering equivalent safety						X								
Repaired, reconditioned or replaced parts shall provide a level of safety that is equivalent to that of the original part						X								
Inspection, repair, maintenance, and modification to be carried out in accordance with manufacturer's instructions or, in the absence of instructions, as approved by a registered professional engineer							X							
Mobile equipment to be operated, inspected, repaired, maintained, and modified in accordance with regulations or the manufacturer's instructions, or in the absence of such instructions, in accordance with good engineering practice											X			
If inspection reveals a condition that might render lifting device unsafe, an employer or supplier shall not require or permit the use of the device until the condition is remedied												X	X	
Employer must set out written instructions on inspection, testing, and maintenance of equipment before it is used for the first time in a workplace														X[1]
Any repair, modification, or replacement of a part of any motorized or manual materials-handling equipment shall at least maintain the safety factor of the equipment or part														X

	BC	AB	SK	MB	ON	QC	NL	NS	NB	PE	YT	NT	NU	CA
Records														
Records for any maintenance, repair, or modification that affects safe performance of the mobile equipment to be kept and to be reasonably available to the operator and maintenance personnel during work hours	X													
Employer must ensure that record of any maintenance carried out is kept at the worksite and is readily available to a worker who operates the equipment		X												
Maintenance and inspection records to be maintained and made reasonably available to the operator and maintenance personnel during work hours							X							
Mobile equipment to have maintenance records for any service, repair, or modification and records to be reasonably available to operator and maintenance personnel during work hours											X			
Employer to keep the inspection, testing, and maintenance report for a period of one year after the report is signed														X

Notes:

[1] The written instructions are to specify the nature and frequency of inspections, testing, and maintenance.

Table A.2-5: Cross-Canada Comparison of Forklift Fuel-related Requirements

	BC	AB	SK	MB	ON	QC	NL	NS	NB	PE	YT	NT	NU	CA
Fuel tank fill point														
Fuel tank fill point or vent opening is not permitted within an enclosed cab of mobile equipment	X													
Employer must ensure that a fuel tank located in the enclosed cab of a powered mobile equipment unit has a filler and vents that extends outside the cab and are sealed to prevent vapours from entering the enclosed cab		X												
Employer must ensure that a fuel tank located in the enclosed cab of a powered mobile equipment unit has a filler and vents that extends outside the cab			X											
Fuel tank location														
Employer and supplier must ensure that the fuel tank of powered mobile equipment is not located in an enclosed cab where provided				X										
Refuelling procedures														
Employer must ensure that a worker does not (a) smoke within 7.5 metres of a vehicle while it is being refuelled, (b) refuel a vehicle when there is a source of ignition within 7.5 metres of the vehicle, or (c) dispense flammable fuels into the fuel tank of a motor vehicle while its engine is running		X												
Worker must not (a) smoke within 7.5 metres of a vehicle while it is being refuelled, (b) refuel a vehicle when there is a source of ignition within 7.5 metres of the vehicle, or (c) dispense flammable fuels into the fuel tank of a motor vehicle while its engine is running		X												
Employer must ensure that a worker dispensing flammable fuel (a) takes precautions to prevent fuel from overflowing or spilling, (b) does not knowingly overfill the fuel system, and (c) does not use an object or device that is not an integral part of the hose nozzle valve assembly to maintain the flow of fuel		X												
Gasoline engines on mobile or portable equipment to be refuelled outdoors, with the engine stopped, with no source of ignition within three metres of the dispensing point, and with an allowance made for the expansion of the fuel should the equipment be exposed to a higher ambient temperature					X									
Hoisting device to have its motor turned off when filling the gas tank						X								
Operator must follow a safe refuelling procedure										X				
Where motorized materials-handling equipment is fuelled in a workplace, a qualified person must do the fuelling in accordance with procedures referred to in the regulation in a place that is well ventilated so that the fuel vapours will be dissipated quickly														X

	BC	AB	SK	MB	ON	QC	NL	NS	NB	PE	YT	NT	NU	CA
Hazardous fuels														
If the fuel tank, compressed gas cylinder, other container, or any associated assembly mounted on motorized materials-handling equipment contains a hazardous substance, the employer must ensure that the tank, cylinder, container, or assembly is (a) located or guarded in such a way that it is not hazardous to the health or safety of a worker who is required to operate or ride on the equipment; (b) connected to fuel overflow and vent pipes that are located in such a way that fuel spills and vapours cannot be ignited by hot exhaust pipes or other hot or sparking parts or be hazardous to the health or safety of a worker required to operate or ride on the equipment; and (c) labelled on its servicing caps or covers as to its contents													X
Propane propelled lift truck														
Employer must ensure that a lift truck propelled by propane has all engine and fuel components designed, assembled, examined, inspected, operated, and maintained in accordance with latest version of CSA B149.2, *Propane Storage and Handling Code*								X						
Installation, operation, and maintenance of propane-fuelled motorized materials-handling equipment to be in accordance with the CAN/CGA-B149.2-M91, *Propane Installation Code,* as amended from time to time														X

A.3 List of Canadian Statutes and Regulations Reviewed

Canadian OHS statutes and regulations reviewed for this project are listed alphabetically below. The versions consulted were as they appeared on December 1, 2024.

A.3.1 Statutes

- *Act respecting occupational health and safety,* CQLR c S-2.1, 1979 (amended 2024).
- *Canada Labour Code, R.S.C., 1985,* c. L-2, 1985 (amended 2024).
- *Occupational Health and Safety Act,* R.S.O. 1990, c. O.1, 1990 (amended 2024).
- *Occupational Health And Safety Act,* RSNL1990 Chapter O-3, 1990 (amended 2023).
- *Occupational Health and Safety Act,* RSPEI 1988, chapter O-1.01, 1988 (amended 2022).
- *Occupational Health and Safety Act,* SA 2020, Chapter O-2.2, 2020 (amended 2023).
- *Occupational Health and Safety Act,* SNB 1983, chapter O-0.2, 1983 (amended 2023).
- *Occupational Health and Safety Act,* SNS 1996, c 7, 1996 (amended 2024).
- *Safety Act,* RSNWT 1988, c. S-1, 1988 (amended 2023)
- *Safety Act,* RSNWT 1988, c. S-1, 1988 (amended by S.Nu. 2020,c.15,s.142(66) and 147(1))
- *Saskatchewan Employment Act*, SS 2013, c S-15.1, 2013 (amended 2024).
- *Workers Compensation Act,* RSBC 2019, Chapter 1, 2019.
- *Workers' Safety and Compensation Act,* SY 2021, c 11, 2021.
- *The Workplace Safety and Health Act,* C.C.S.M. c. W210, 1987 (amended 2024).

A.3.2 Regulations

- *Canada Occupational Health and Safety Regulations,* SOR/86-304, 1986 (amended 2023) at ss 14.1, 14.8, 14.20, 14.23, 14.24, 14.41.
- *General Regulation – Occupational Health and Safety Act,* NB Reg 91-191, 1991 (amended 2023) at s 216.
- *Industrial Establishments,* R.R.O. 1990, Reg 851, 1990 (amended 2022) at ss 51, 61.
- *Occupational Health and Safety Act General Regulations,* PEI Reg EC180/87, 1987 (amended 2021) at ss 33.1, 33.2, 33.3.
- *Occupational Health and Safety Code,* Alta Reg 191/2021, 2021 at ss 256, 257, 260, 274, 279.
- *Occupational Health and Safety Regulation,* BC Reg 296/97, 1997 (amended 2023) at ss16.1, 16.3, 16.17, 16.43.
- *Occupational Health and Safety Regulations,* 2012, NLR 5/12, 2012 (amended 2022) at ss. 250, 251, 252, 254, 267.
- *Occupational Health And Safety Regulations,* C.R.Nu. R-003-2016, 2016 (amended 2021) at ss 205, 207, 208, 210, 222, 223.
- *Occupational Health and Safety Regulations,* NWT Reg 023-2015, 2015 (amended 2024) at ss 205, 207, 208, 210, 222, 223.

- *Occupational Health and Safety Regulations,* S-15.1 Reg 10, 2020 at ss 11-2, 11-3, 11-4, 11-6, 11-12, 13-1, 13-6, 13-18, 13-19.
- *Occupational Safety General Regulations,* N.S. Reg. 53/2013, 2013 at ss 81, 82.
- *Regulation respecting occupational health and safety,* CQLR c S-2.1, r 13, 2001 (amended 2015) at ss 256, 256.2, 256.3, 272.
- *Workplace Health and Safety Regulations,* Y.O.I.C 2006/178, 2006 (amended 2022) at ss 6.01, 6.02, 6.03, 6.04, 6.05, 6.06, 6.30.
- *Workplace Safety and Health Regulation,* M.R. 217/2006, 2006 (amended 2019) at ss 22.3, 22.14, 22.15, 22.28, 22.29.

Appendix B – Outcome of the Review of CSA B335

B.1 Recommendations for Considerations for Amendments to CSA B335

Table B.1: Amendments and Additions to CSA B335 to Address Hydrogen as a Lift Truck Fuel Source

Section of the Standard	Suggested Amendments/Additions
2 Reference Publications	The following reference publications could be added: ▪ CSA/ANSI HGV 2:23, *Compressed hydrogen gas vehicle fuel containers* (specifically automotive) ▪ CSA/ANSI HGV 3.1:22 *Fuel system components for compressed hydrogen gas powered vehicles* (specifically automotive) ▪ CSA/ANSI HPRD 1:21 *Thermally activated pressure relief devices for compressed hydrogen vehicles (HGV) fuel containers* ▪ CSA HPIT 2:17 *Dispensing systems and components for fueling hydrogen powered industrial trucks* (specific to industrial trucks) ▪ CSA HPIT 1:15 *Compressed Hydrogen powered industrial truck on-board fuel storage and handling components* (specific to industrial trucks) ▪ ANSI/UL 2267 *Standard for Safety Fuel Cell Power Systems for Installation in Industrial Electric Trucks* ▪ ANSI/NFPA 2:2024 *Hydrogen Technologies Code* ▪ SAE J 2601-3-2022 *Fueling Protocol for Gaseous Hydrogen Powered Industrial Trucks*
3 Definitions	The following acronyms and definitions could be added: ▪ HPIT – Hydrogen Powered Industrial Trucks ▪ HGV – Hydrogen Gas Vehicle ▪ CGH – Compressed Gas Hydrogen ▪ CH2 – Compressed Hydrogen ▪ FCPS – Fuel cell power system ▪ FCEV – Fuel cell electric vehicle ▪ BRM – Battery replacement module
4 General Requirements	
4.5.1.3 Hazardous Locations	An explanatory note could be added to this section indicating that there is currently no requirement in Chapter 9.5 of NFPA 505 that CGH vehicles be marked.
4.5.2.1 Ventilation	This section could be amended to reflect that proper and adequate ventilation is required in enclosed areas where hydrogen-powered forklifts are used to prevent the build up of any hydrogen released from the lift truck.

Section of the Standard	Suggested Amendments/Additions
4.5.2.2 Ventilation	The explanatory note following this section could be amended to reflect that hydrogen releases can deplete oxygen within enclosed spaces and can create an explosion hazard.
4.5.4 Noise	This section could be amended or an explanatory note could be added to reflect that fuel cell electric vehicles are much quieter than conventional forklifts. Users within the facility should be trained to recognize an approaching CGH-powered forklift.
4.6.1 Lift truck selection criteria General	This section could be amended to add hydrogen-powered vehicles to the prohibition on the use of lift trucks powered by gasoline, liquefied petroleum gas, or diesel where explosive concentrations of flammable gases or vapours might be present or in areas where exhaust gases might accumulate.
4.8.5.2 Warning devices	This section may require an explanatory note to emphasize that because fuel cell electric vehicles are extremely quiet, additional warning devices may be needed to make others aware of the fuel cell electric vehicles operating in the facility.
4.8.6.3 Stability	This section could either be amended or an explanatory note could be added that when battery electric forklifts are converted to fuel cell forklifts, the replacement parts may be of differing weight or weight placement, which could change or compromise the forklift's centre of gravity and reduce the load capacity outside of the vehicle's marked parameters.
4.9.1 Safe Operating Procedure Preoperation inspection	This section may require an explanatory note that the pre-operation inspection of a hydrogen-powered forklift should include a process for detecting hydrogen releases. See note below on suggested amendment of Annex A.
4.9.13.2 Fuel handling and storage	This section could be amended to address the storage and handling of hydrogen gas fuel. The amended section could note that the storage and handling of hydrogen shall comply with the authority having jurisdiction and, in the absence of such requirements, shall be in accordance with NFPA 2:2024. An explanatory note could point the reader to the relevant chapters in NFPA 2.
4.9.13.3 Refuelling a fixed LP gas cylinder	This section could either be amended to include refuelling of hydrogen-powered forklifts or a new section could be added to provide guidance for refuelling hydrogen with compressed hydrogen gas. The amended section should reference both NFPA 505 and NFPA 2.
4.9.14 Changing and charging storage batteries for electric trucks	This section could be amended or another section could be added to add specific language about hydrogen fuel cell batteries. It may be helpful to add an explanatory note that refers the user to requirements in Chapter 9.4 of NFPA 505.
6 Operator Training Requirements	
6.5 Lift truck features and safety equipment	This section could be amended to include training on the powertrain of the individual unit(s) the employer has in service, the hazards associated with them, the safety precautions specific to that type of unit, and the specific engineering controls within the facility to address hazards. Alternatively, an explanatory note could be added to clarify that subsections (a) and (b) should include this information.

Section of the Standard	Suggested Amendments/Additions
6.6 Stability	This section could include an explanatory note that highlights how the conversion of an electrically powered truck to a fuel cell–powered electric industrial truck may impact stability and the lift truck's centre of gravity.
6.8 Preoperational inspection	This section could include an explanatory note incorporating guidance from Chapter 9 of NFPA 505 that a match or open flame shall not be used to check for leaks in compressed gas hydrogen fuel systems.
6.16 Workplace-specific hazards	This section could be amended or an explanatory note could be added to include that the trainees on hydrogen-powered forklifts shall be instructed on the accumulation of hydrogen in enclosed spaces and the possibility of hydrogen leaks during refuelling and battery changes.
6.17.1 Shutdown	This section could be amended to incorporate guidance from Chapter 9 of NFPA 505 that compressed hydrogen gas fuel cell system–powered lift trucks shall not be parked near sources of heat or open flames or similar sources of ignition.
6.18.1 Refuelling/ recharging General	This section could be amended to include the trainee being instructed on workplace-specific elements intended to protect the area or the facility from the flammability of hydrogen (e.g., gas sensors, infrared flame detection, ventilation).
6.18.3 Refuelling other hydrocarbons (diesel, gasoline, natural gas, and propane)	This section could be amended to reflect that hydrogen is a fuel source.
6.18.4 Battery recharging / exchange	This section could include an explanatory note that, in accordance with NFPA 505, only trained and authorized personnel are to change replaceable fuel cell system. modules in hydrogen-powered forklifts (i.e., Type CGH trucks) or replace batteries in electric forklifts (i.e., Type E trucks) with fuel cell system modules.
6.20.2 Knowledge verification	This section could be amended to include that all trainees shall be evaluated on the hazards of hydrogen-powered forklifts, as well as hydrogen-specific elements in the preoperational inspection.
7 Qualifications of the Lift Truck Trainer	
7.3 Knowledge	Subsections (g) and (h) of this section could be amended to incorporate hydrogen fuel cell systems.
8 Maintenance and Repair Practices	
8.1.3 General	This section could be amended to include that samples of generic inspection checklists for hydrogen-powered lift trucks are provided in Annex A.
8.3.2 Precautions before starting inspections	This section could be amended to include the specific precautions to be taken for hydrogen power trains.

Section of the Standard	Suggested Amendments/Additions
8.3.4 Precautions before starting inspections	This section could be amended to include that a match or open flame shall not be used to check for leaks in compressed gas hydrogen fuel systems.
8.3.5 Precautions before starting inspections	This section may require amendment or an explanatory note about the need to properly and adequately ventilate the space to ensure that there is no build up of hydrogen. An explanatory note should be included that references the relevant requirements on repair garages in NFPA 2.
8.5.2 Additional maintenance and repair precautions	This section could be amended to include that special consideration shall be given in the case of a leak in the fuel and the fuel cell system. An explanatory note illustrating the hazards of a hydrogen leak may also be helpful.
8.5.11 Additional maintenance and repair precautions	This section could be amended to include that replacement fuel cells for hydrogen-powered lift trucks shall be of the same service weight that falls within the maximum/minimum range specified by the truck manufacturer.
9 Competence of Maintenance Technicians	
9.1 Competence of maintenance technicians **General**	This section could include an explanatory note that only trained and authorized personnel shall change fuel cell system modules on hydrogen-powered forklifts.
Annexes	
Annex A **Sample inspection checklists**	A sample preparation inspection checklist and a service/inspection report for technicians that are applicable to hydrogen-powered lift trucks could be developed and added to the Annex. These checklists could incorporate elements listed in relevant NFPA standards.
Annex D **Batteries and battery charging**	This Annex could be amended to include information on fuel cells and charging requirements for hydrogen-powered lift trucks, as well as the unique requirements for hydrogen refuelling stations. Relevant elements in NFPA 505, NFPA 2, and SAE J2601 should be incorporated.
Annex F **Example operator evaluation form**	Table F.1 in this Annex could be amended to include refuelling procedures for hydrogen-powered forklifts. These procedures should incorporate or be informed by relevant procedures in NFPA 505 and NFPA 2.

CSA Group Research

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