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Executive Summary

The objective of this NREL report is to provide information on codes and standards that would ease the implementation of emerging fuel cell technologies. This information should help project developers, project engineers, code officials and other interested parties in developing and reviewing permit applications for regulatory compliance.

Specifically, this report reviews the codes and standards of two emerging hydrogen powered fuel cell technology markets; forklift trucks and backup power units. It includes hydrogen indoor fueling equipment and outdoor bulk hydrogen storage systems associated with these markets.

The fuel cell backup power units fit well in applications where a power outage would have serious negative consequences and have high reliability, low maintenance, and clean operation. Hydrogen powered fuel cell forklift trucks are becoming cost competitive with battery powered ones due to productivity gains that offset the costs of converting the trucks to hydrogen and installing the fueling infrastructure. The Defense Distribution Depot Susquehanna Pennsylvania (DDSP) converted half of their fleet of eighty forklift trucks to run on hydrogen-powered fuel cells in 2009. The Marine Corps Logistics Base (MCLB) located in Barstow, CA will install a hydrogen powered fuel cell power plant to be used for backup power at the base fire station. The DDSP installation involves the installation of bulk liquefied and gaseous hydrogen storage facility, construction of indoor hydrogen dispensers, and the forklift truck conversion. The MCLB installation requires the installation of a stationary fuel cell and the associated hydrogen storage. The DDSP installation is more complex and uses both cryogenic hydrogen storage and high-pressure gaseous hydrogen storage. The operation of the DDSP installation also involves far more personnel. The bulk hydrogen storage system must be refilled and maintained. The dispensing systems must be operated by trained personnel. The forty hydrogen-powered forklifts require forklift operators. Additionally, the forty forklifts must be maintained by personnel from the two companies that performed the forklift conversions or provided new forklifts. Twenty of the forklifts in operation were conversions of existing forklift trucks and twenty are new forklift trucks. The operation of the fuel cell at MCLB requires only infrequent replenishment of the hydrogen fuel.

As a result of the differences in the complexity of these two operations, the codes and standards requirements they are subject to vary significantly and the level of effort required to achieve regulatory approval also varies proportionately. In both cases, the Authority Having Jurisdiction (AHJ) is the facility owner. They are both Department of Defense (DoD) facilities subject to the Unified Facilities Criteria 03-600-1 Fire Protection Engineering for Facilities. This document contains safety requirements but also refers out to and requires compliance with the International Building Code (IBC) and the National Fire Codes (NFC).

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I Introduction

The deployment of hydrogen fuel cell systems is expanding as a clean and efficient alternative to fossil fuels. Fuel cells have been shown to be a cost-effective alternative to conventional power systems. Fuel cells have found applications in backup power systems for buildings, power systems for electric-drive forklifts, lighting, backup power in the communication industry, as well as power systems for passenger and commercial road vehicles. One impediment for facile deployment is that permitting officials are oftentimes unfamiliar with these new technologies, even though the underlying codes and standards have been developed. Herein we review the deployment of two emerging hydrogen technologies--hydrogen powered forklifts and hydrogen powered stationary fuel cells for backup power. These two projects are at different levels of maturity. Whereas the hydrogen powered forklift deployment is an on-going and growing deployment, the implementation of the stationary fuel cell for backup power has been proposed but remains in the planning phase. A description of the two technologies will be presented, along with issues and lessons learned encountered during the permitting process and deployment, as well as an assessment of the field performance of the technology employed for the forklift project. The main focus of this report, however, is to facilitate the permitting process by providing to officials, end-users and other interested parties a comprehensive survey of the pertinent codes that apply to the two case studies addressed herein.

II The Defense Distribution Depot Susquehanna, PA (DDSP)

The Defense Distribution Depot Susquehanna, Pennsylvania (DDSP) is a major distribution depot operating in support of Department of Defense (DOD) off-shore activity, including Afghanistan and Iraq and is managed by the Defense Logistics Agency (DLA) of the DOD. The material support does not include munitions, fuels, or other materials that could pose significant fire or reactivity hazards. The DDSP also does not store food, which eliminates the need for refrigeration or air-conditioning and allows for the use of propane powered forklift trucks. Material within the depot is loaded on to trucks for road transport to an air deployment center. Operation at DDSP is essentially 24/7 around the clock, but the heaviest activity is during the weekday day shift with lower activity during evenings, nights, and weekends. The DDSP operations are critical to DOD, and the loss of the building and its inventory management capability would have a significant adverse impact on the ability of DOD to fulfill its mission in Iraq, Afghanistan, and other operations. Thus, the implementation of new technology, such as hydrogen-powered forklifts, was rigorously scrutinized for assurances of safe and reliable deployment and operation. Although some buildings within the Susquehanna complex are nearly 100 years old, the DDSP Storage facility is approximately 20 years old. The distribution depot is a building of 1.8 million square feet, with an elevated ceiling with a height of 25 feet or greater.

An overview of site operations and a review of the underlying codes and standards as they pertain to the deployment of hydrogen-powered fuel cells are presented below.

II.1 The DDSP Hydrogen-Powered Forklift Deployment

The DDSP was selected for deployment of hydrogen-powered forklifts. The DDSP project is part of a larger alternative energy deployment program supported by the Department of Defense, to utilize hydrogen powered forklifts within DLA facilities. The DDSP site was selected by the DLA to demonstrate the viability of hydrogen-powered forklifts and the required support systems, especially indoor hydrogen dispensing, and to assess the performance relative to conventionally-powered forklifts. The DDSP warehouse is very large and as such it has been argued that it simulates the characteristics of an outdoor space for hydrogen releases [1.] Personnel from the NREL Codes and Standards Group performed a third party codes and standards compliance review during the initial permitting process for this project in 2008 [2]. The size of the original hydrogen power forklift fleet during the initial deployment phase was 40. Although the first phase of the project was completed in February 2011, the hydrogen-powered forklift fleet remains operational and has expanded to 55 forklifts, including the original 40. The use of hydrogen-powered forklifts and associated support systems (dispensing, storage) at the DDSP represents an active, on-going, and successful deployment of emerging fuel cell technologies. Although the site is self-insured, *Factory Mutual* did set up and held a meeting at the DDSP for formulating parameters for underwriting other hydrogen deployments.

II.1.1 Site Visit and Review of the DDSP Site Operations

On August 4, 2010 Carl Rivkin, Robert Burgess, and William Buttner of the NREL Hydrogen Codes and Standards Group made a site visit to the DDSP to review and assess the on-going hydrogen fuel cell powered forklift program. Mr. Robert Skinnell, Equipment Services Manager at the DDSP, was the primary point of contact and escort for the duration of the site visit. The focus of the site visit was to review the forklift operations with emphasis on safety and on codes and standards compliance. The occurrence of possible adverse and unexpected events was specifically addressed during the site visit. The building and operations are self-insured. Nevertheless, loss of the DDSP support operations could have severe adverse impact on DOD off-shore operations. In addition to safety and compliance to codes and standards, operational efficiency (e.g., performance, reliability, design strengths, design limitations, operator's perceptions) and future plans of the hydrogen powered forklifts were addressed during the site visit. Information exchange was achieved primarily through interaction between NREL and DLA site personnel.

The facility was not air conditioned, except for some office areas, and thus could get quite warm. On the day of the NREL site visit, the outdoor temperature was above 90ºF, and there was also high humidity. Large ceiling fans were mounted on the ceiling for ventilation. The potential impact of the large ceiling fans on other fire suppression systems (e.g., the ceiling fans may alter air and heat dispersion patterns which then might impact triggering of sprinkler systems) was discussed. Because of these concerns a decision was made by site personnel that the fans are to be turned off in the event of a hydrogen release. Although the outdoor temperature was hot, the indoor temperature within the facility was not overly uncomfortable. Apparently however, temperatures can still get quite warm within certain spaces (e.g., loading and unloading trucks), which is exacerbated by the heat generated from the fuel cells. Heaters are used in winter in the DDSP facility to maintain a reasonable indoor working temperature during the cold months.

The deployed Material Handling Equipment (MHE) includes approximately 80 forklifts. Of these, there are 20 hydrogen-powered forklifts (Forklift Model 1) that were provided by Manufacturing Team 1, comprised of a forklift manufacturer and a fuel cell stack manufacturer (Fuel Cell Developer 1), and 20 hydrogen-powered forklifts (Forklift Model 2) provided by Manufacturing Team 2, which was also comprised of a forklift manufacturer and a fuel cell stack manufacturer (Fuel Cell Developer 2). The hydrogen-powered forklifts were retrofitted from battery-powered forklifts that were modified to accommodate the fuel cell power systems. Both forklift systems were 4000 pound forklifts. Forklift Model 1 system had a slightly wider frame, which had an impact on performance by allowing the installation of alternative, larger capacity fuel tank. The deployment of the 40 forklifts was part of a 2-year deployment supported by the Department of Defense [3] and was initiated in February 2009 and scheduled for completion in February 2011. The remaining 40 forklifts are mostly battery powered with a few systems powered by propane. Robert Skinnell indicated that he plans to continue and expand the deployment of the hydrogen powered forklifts after completion of the pilot program in February 2011. This is the case, and as of March 2011, the hydrogen forklifts were still operational and the fleet has expanded to 55. The additional 15 forklifts were a third model type [R. Skinnell, Personal Communication March 16, 2011][4] using Fuel Cell Developer 2 fuel cells.

Mr. Henry Hoffman, Fire Chief at the DDSP facility, was involved with the initial approval process for the hydrogen-powered forklift demonstration. At the beginning of the proposed deployment Mr. Hoffman stated that he had a concern about the operation of hydrogen fuel cell forklifts within the facility, due in part to a lack of historical data on their operation, especially a lack of data on their safety record. He believed that the critical mission fulfilled by the depot necessitated caution. During the planning phase of the project, he was opposed to the proposed indoor fueling. Ultimately, however, indoor fueling systems were installed within the DDSP. The fueling system included the hydrogen dispensers (also called the fueling station) which delivery to the hydrogen forklifts. At one time a centrally located fueling station within the facility was proposed, but this would have required piping of hydrogen from the outdoor storage facility to the indoor dispensing station. To minimize the piping network, a decision was made that required that the dispensing station to be located on the indoor wall adjacent to the outdoor storage facility. The down side to this decision was that a portion of the fuel cell forklift fleet would operate several hundred meters away from the dispensing units, and thus require additional transit time.

The safety systems installed with the dispenser units were also discussed. Hydrogen sensors are installed around the dispensing units (one above and one internal to each dispensing unit). The sensors are designed to shut down the flow of hydrogen if an upset condition is detected. Mr. Hoffman stated that he insisted that the sensor alarms would also be wired into the site fire alarm system; this appears to be the case for the operational system. The outdoor storage system also has sensors including heat trace sensors. However, site personnel reported that there had been no significant safety incidents associated with the operations of the forklifts, the indoor dispensing, and the outdoor hydrogen storage system. Based upon the design of the dispensing system and on the operational experiences at the DDSP, Mr. Hoffman stated that indoor fueling and hydrogen forklift operation could be performed safely at the facility. As of March, 2011, the forklift and support systems have been safely operating at DDSP for nearly 2 years [5].

II.1.2 The Hydrogen Dispensing and Storage Facility

Refueling of the hydrogen forklifts is performed at one of two hydrogen dispensing units, both of which are located together along an inside wall adjacent to the outdoor hydrogen storage facility. Maintenance and design of the dispensing units and storage facility were and remain the responsibility of a commercial hydrogen producer and supplier. Inspections and required maintenance are performed on a weekly basis. A contract is in place with the hydrogen supplier to provide hydrogen and to support the maintenance activity of the site dispensing and storage system. The hydrogen supplier also maintains the safety system for the dispenser and storage tanks. The safety system includes the use of hydrogen detectors, but no specific details were available during the site visit on the maintenance schedule of the dispensing units or the sensors. It can be assumed that calibration is performed as specified either by the sensor manufacturer or by the hydrogen supplier's policy for safety sensors.

A queue of three forklifts, all of the Manufacturer Team 2 design, was waiting for fuel at the time of the NREL visit. The Forklift Model 2 tank capacity was 0.5Kg, but each of the three trucks took only between 0.25 and 0.35 Kg during the fill. Multiple refuelings of the Forklift Model 2 units are required during a shift. With the exception of connecting the dispenser fueling hose to the forklift, the fueling operation is automated and fail-safe in that if proper connections or communication is not established between the forklift and dispenser, fueling will not proceed. Hydrogen refueling was performed by a dedicated personnel specifically assigned to operate the dispensing units, although Robert Skinnell was proposing to have lift operators refuel their own vehicles. This is currently being negotiated with the forklift operator union. If approved, operators will receive thorough training on operation of the dispensers. The training will also include a transition period during which time a person highly trained in the dispenser operations will be present during all fills performed by lift drivers. Refueling by forklift operators would allow for opportunistic refueling and lower the number of required personnel to perform site operations, which could represent a significant cost savings. The dispenser operator reviewed the fueling procedure with NREL personnel. The dispenser nozzle is attached to the forklift (a mechanical slider secures the nozzle in place). Upon installation of the nozzle, feedback between the forklift and the dispenser verifies the connection and performs critical measurements (e.g., the pressure in the storage tank). Once the checkout is complete, the fueling operation can proceed, which for the Forklift Model 2 system requires approximately 40 seconds. Apparently forklift information is automatically logged during the fill (presumably to keep track of hydrogen use, lift ID number, hours of operation and other parameters). While NREL personnel were present, both dispensers successfully completed a fill. However, when a second fill was attempted on dispenser 1 (when facing the wall, the dispenser on the left) the system failed to get appropriate pressure feedback; the forklift had to move to the other dispenser to perform the fill.

The fill was completed using dispenser 2 without a problem. Later in the day, Mr. Skinnell independently noted to the NREL group that one dispenser was less reliable than the other, and indicated that the problem was associated with the Infra Red (IR) ring, which provides communication between the forklift and dispenser unit. In contrast to the Forklift Model 2 design, the Forklift Model 1 system has a tank capacity of 1.5Kg of hydrogen (at 5000 psi, although the storage tank can operate up to 10000 psi) and a fill can take several minutes. However, with a full tank, the Forklift Model 1 system can normally operate on a full 8-hour shift without refueling.

No release or adverse event was ever recorded due to the dispensing units. However, during the development of the outdoor storage facility, hydrogen tube trailers were temporarily used to keep the DDSP facility supplied with hydrogen. The trailers were outdoor systems. At one point during the development of the outdoor storage facility a hydrogen sensor installed within the control box of the tube trailer system indicated the presence of hydrogen. A subsequent inspection with handheld monitors confirmed a leaky connection. There was no significant adverse event (fire, bursting, etc.) as a result of this event. Although only minimal details on this release were available from DDSP personnel, additional details of this are reportedly on-file within the NREL Technology Validation program [6]. The hydrogen supplier would also have additional details, but their records were not available to NREL. Nevertheless, it is noted herein that the use of a hydrogen sensor as an independent component of the safety system successfully warned of a leak in the outdoor storage facility prior to an adverse event.

The DDSP hydrogen storage facility is outdoors along the wall adjacent to the indoor dispenser units. The storage units are approximately 30 feet from the building and comprised of a large storage tank with a capacity in excess of 9000 gallons of liquid hydrogen. This tank is connected to a bank of gaseous hydrogen storage tanks. The hydrogen is piped as a gas to the dispensers. There is no on-site production, so all hydrogen is transported to the site with land vehicles. Steam Methane Reforming for on-site hydrogen production had been considered for the DDSP. However, there were purportedly operational issues with the SMR process at a DLA facility in Georgia, and therefore all hydrogen is trucked in to the DDSP facility. The delivered cryogenic hydrogen has worked out well for the DDSP. An unofficial estimate for the cost of hydrogen was $7/Kg, which, according to the Forklift Model 1 field engineer present at the DDSP facility during the NREL site visit, corresponds to approximately $1.00 per hour of operation. These are only rough estimates however, and neither cost parameter has been validated. The storage facility includes pumping stations. As with the dispensers, design, operation, and maintenance are performed by the hydrogen supplier. It was reported by DDSP personnel that the initial development of the storage facility required extensive maintenance work by the hydrogen supplier. However, Robert Skinnel noted that at no time was hydrogen unavailable to support the required operations within the Depot, although at one time, one of the two dispensers was down for several days over a weekend, and thus required site operations to proceed without a backup fueling facility. Robert Skinnell noted that the hydrogen storage capacity greatly exceeds the demands for all the hydrogen forklift operations. Thus there is sufficient hydrogen capacity to support other hydrogen technologies, including the hydrogen powered bus which had been scheduled for delivery to the DDSP, as well as the possible expanded use of hydrogen powered forklifts within the DDSP. Additional hydrogen powered forklifts and other vehicle types have since been acquired by the DDSP, but the hydrogen bus program did not materialize [7].

II.1.3 The Hydrogen-Powered Forklifts

At the time of the NREL site visit, there were two different model hydrogen-powered forklifts in operation at the DDSP, including 20 forklifts provided by Manufacturing Team 1 and 20 forklifts provided by Manufacturing Team 2. Two groups of DDSP forklift operators have been trained for operating the prototype forklifts. One group is dedicated to the Forklift Model 1 system, the other group to the Forklift Model 2 system. Operators are typically assigned a forklift at the beginning of the shift. In other words, as a general rule they do not operate "their personal" truck, although there seems to be some exceptions to this (specifically, one driver has chosen one truck as her own, in part because she maintains it cleanliness and readiness to her liking).

Both the Forklift Model 1 and Forklift Model 2 vehicles are specified for 4000 pound capacity, although the Forklift Model 1 units have a wider platform. Forklift Model 1 units were installed on forklift platforms with a wider base, which accommodated a 1.5 Kg capacity storage tank. In contrast, the Forklift Model 2 units had a 0.5Kg capacity storage tank. The difference in tank capacity had a significant impact on the capability of the respective forklifts. The Forklift Model 1 system with a 1.5Kg tank could operate 8 to 10 hours on a single fill, predicated of course on the specific work load. Nevertheless, operators felt they could run the truck for a full shift (8 and possibly even 10 hours) on a single fill. This was viewed as a very important positive feature for Forklift Model 1 and dramatically affected perception of the relative overall performance of the two forklift models. In contrast, the Forklift Model 2 system, with a 0.5 Kg capacity tank required multiple fills for a single shift. The NREL team was informed that Fuel Cell Developer 2 projected 8 hour operation time on a single fill had they been able to install a 1.5Kg hydrogen storage tank on the forklift. Operator ratings, hence salaries, are predicated upon their productivity. Forklift down-times, such as refueling or battery change outs, will adversely impact productivity. Thus, at best, operators viewed the multiple fills as an inconvenience, but one that will decrease their productivity. In contrast to operator's perception, site personnel indicated that Forklift Model 2 outperformed Forklift Model 1 in terms of overall reliability and maintenance requirements.

During the NREL visit, representatives from the Fuel Cell Developer 1 and Forklift Model 1 were on-site at the DDSP facility performing regular/routine maintenance on a forklift. Representatives of Manufacturing Team 1 have a regular presence at the DDSP facility, maintaining their fleet of forklifts. During the NREL site visit, the compressor that controls air intake was being overhauled. However, the maintenance by Fuel Cell Developer 1 personnel did not affect operator's use of the forklifts and forklifts were available for all required activity. The Manufacturing Team 1 site representatives described issues and performance details associated with the operation of the Forklift Model 1 system. Currently, fuel cells with over 4000 hours of operation are in use at the DDSP facility, and the proposed/expected lifetime is 10000 hours. When new, the open circuit potential of each cell (there are 90 cells in each fuel cell pack) is

0.9V; the lifetime is defined as when one cell is at a Voc of 0.6 V. The cells are capable of outputting 50 amps at 72V, but the voltage is regulated down to 36V with internal circuitry. An internal capacitor pack levels the power output under heavy demands. Chemical filters, possibly two in series, scrub the air intake. There are two hydrogen sensors installed within the case to monitor for leaks. These sensors would be good test candidates for the NREL Safety Sensor Test Laboratory [8].

II.1.3.1 Comparison to Battery Powered Forklift Systems

Hydrogen-powered forklifts are considered as potential replacements to conventional battery-powered forklifts. The conversion to fuel cell systems can have significant advantages associated with improved productivity. There are several significant short-comings associated with the use of battery packs in forklifts. Recharging and change out times are obvious issues. Battery maintenance is another concern. Conventional battery systems will need periodic replacement of water, and failure to maintain proper water levels will shorten the working life of the battery pack. In response to this, several years ago the DDSP obtained Gel-Pack battery systems for use in battery-powered forklifts. Since the GelPack is a sealed design, this battery system does not require water replenishment. Circumventing the water maintenance requirements was viewed as highly advantageous because water management, which as a manual operation, was not always performed as needed, resulting in a shortened battery lifetime. Unfortunately, the GelPacks however have aged, and whereas a new pack could hold sufficient charge for a full shift (or close to a full shift), the battery's capacity degraded as the pack aged. Multiple battery pack change outs are now required to power a forklift for a full 8-hour in a shift, and this adversely impacts productivity. Since the GelPacks have decreased capacity that precludes 8-hour operation, another alternative battery pack system has been acquired. The new battery packs, which cost about $4000 per pack, are of the classic design that requires water replenishment. The new packs have, however, a capacity that can last for a full 8 hour shift of conventional forklift use. There have also been dramatic upgrades in the battery charging facility within the DDSP. A new, multimillion dollar facility for battery change out, charging, and maintenance is now on-line. A discharged battery pack can be removed from a forklift and replaced with a fully charged pack in about 4 minutes. Thus, the forklift operational time with a fully charged battery is comparable to the forklift operational time achieved with a full 1.5Kg capacity tank. The battery change-out time and hydrogen-fueling time are also comparable. Thus, loss of productivity due to "down times" is comparable for the hydrogen-powered and battery-powered forklifts. The new battery packs are expected to have a 5 year lifetime, although it is not yet clear whether the new batteries will maintain such large capacity after they have been in service for several years. In addition to rapid battery exchange, the new charging station has the capability of monitoring the state of the battery (including charging, water maintenance schedule, etc.) that will alert site personnel of the need to add water, although actual water maintenance activity will still be performed manually. Battery maintenance within the DDSP, including water management issues, are now specifically the responsibility of dedicated charging station personnel, and this adaptation has improved compliance to battery maintenance requirements. There remains one significant operational advantage of the hydrogen fuel cell forklifts relative to battery powered systems. The power, which the fuel cell will deliver will not degrade during operation (i.e., as the hydrogen fuel in the tank is used), whereas the available power stored within the battery will degrade as the battery is discharged through use. The ability to maintain full operational power translates to increased productivity.

II.1.3.2 Forklift Operators

A critical review of forklift performance (real and perceived) was obtained from discussions with several operators. Specifically NREL personnel obtained feedback from three Forklift Model 1 operators and two Forklift Model 2 operators. The perceived performance capabilities of Forklift Model 1 and Forklift Model 2 were significantly different. The major factor for this difference was the maintenance and operational requirements of the two designs. Forklift Model 1 was installed with a 1.5 Kg hydrogen storage tank, which allowed for 8 to 10 hours continuous operation, whereas Forklift Model 2 was installed with a 0.5Kg hydrogen storage tank, which required multiple refuelings per shift. Fueling operations translated into more downtime during a normal 8 hour shift, and this adversely impacts productivity (although operators were not penalized for downtime at the DDSP). The use of hydrogen powered forklifts was a deployment project, implemented in part to help develop products and markets for emerging technologies. Thus, prototype systems (that is, experimental, pre-production systems) were used. Nevertheless, operators of Forklift Model 1 expressed enthusiasm for the technology and would like to keep the system. The ability to maintain full power regardless of hydrogen level in the tank was viewed very highly. Conversely, Forklift Model 2's internal diagnostic system (warning lights) was complicated and not intuitive. This, coupled with the multiple refueling requirements, led to a less than enthusiastic view of the forklift. The NREL team was informed that Fuel Cell Developer 2 projected 8 hour operation had they been able to install a 1.5Kg.

II.1.4 Events, Failures, and Incidental Issues

There have been no reportable releases of hydrogen that impacted or potentially impacted site operations or that posed a significant risk to the facility [9]. Furthermore, overall performance of the support systems (storage and dispensers) and forklifts were such that the operation of the DDSP facility was not adversely affected. The hydrogen sensors at the dispenser detected no hydrogen releases; nor did NREL personnel hear of any releases detected by the sensors installed in the Forklift Model 1 (NREL personnel received no information indicating that sensors are or are not installed in the Forklift Model 2 trucks, but it is likely that some sensor technology is present). There were however, some less than ideal events and performance observations. One dispensing unit appears to have problems. This was even observed during our site visit when one truck had to move from dispenser 1to dispenser 2 for refueling. Although relocating to the second dispenser unit for refueling took only a couple of minutes (40 seconds or so for the actual fill), a significant impact could occur if the second dispenser failed. The nozzle was replaced, apparently due to support hardware associated with communication between the forklift and the dispenser. Robert Skinnell noted the existence of problems during the development of the hydrogen storage and transport system (to the dispensers), and that engineers for the hydrogen supplier made frequent trips to DDSP during the initial installation of the facility.

In terms of operation, the forklifts and infrastructure performed as well as conventional battery technology. Normal routine operations (refueling time and frequency during a shift) require comparable time to conventional systems (battery exchange time and frequency during a shift). The hydrogen support systems never had a failure that shut down operation. Nor had there been an event associated with the hydrogen support systems that posed a safety risk. The safety sensors at the dispensers never had a false alarm. Safety sensors in the developmental (and temporary) outdoor storage system did identify a leak.

II.2 Comprehensive codes and standards evaluation

The list of codes and standards citations contained in Table 1. Code and Standards Citations for Bulk Hydrogen Storage Facilities and Indoor Hydrogen Dispensing Operationscontain the most commonly used codes and standards for the installation and operation of stationary hydrogen fuel cell power systems.

Table 1 is an extensive listing of codes and standards that apply to indoor hydrogen dispensing operations and hydrogen storage systems. The table is not a complete listing of all of the codes and standards citations but instead lists key requirements or sections of documents.

Unified Facilities Criteria (UFC 3-600-1, 26 September 2006) Fire Protection Engineering for Facilities, the Department of Defense document prescribes the use of the safety codes in the following subsections when performing a fire safety analysis.

II.2.1 Absence of Criteria

The UFC gives the following guidance for determining which requirements apply to a specific component or process. When a specific application is not covered by the criteria cited in the UFC, follow national building codes, recognized industry standards, and standard engineering practices. In the absence of such technical information, contact the DOD component authority having jurisdiction (refer to paragraph 1-4.6).

Code review for the hydrogen fueling operation using the UFC directed codes.

USC, Title 15, Section 272, identifies the necessary consensus technical standards required to implement policy objectives and activities within the area of fire protection engineering for the DOD. Compliance with criteria issued in accordance with this UFC does not constitute an exception to the public laws. Fire protection criteria must conform to the requirements of this UFC, the *National Fire Codes*, published by the National Fire Protection Association (NFPA), except as modified by this UFC, and portions of the *International Building Code (IBC)*, published by the International Code Council, as specifically referenced by this UFC. Additional criteria include portions of the Factory Mutual Global *Property Loss Prevention Data Sheets (FM Global Data Sheets)*, as specifically referenced by this UFC. Buildings required to be accessible must meet the provisions of Federal Standard FED-STD-795, *Uniform Federal Accessibility Standard (UFAS)* at http://www.access-board.gov/ufas/ufas-html/ufas.htm, and the

Americans With Disabilities Act Accessibility Guidelines (ADAAG) at http://www.access-board.gov/adaag/html/adaag.htm.

Note 1: UFC 1-200-01 identifies the base line building code as the *International Building Code* to be used for all DoD construction. NFPA 5000 *Building Construction and Safety Code*, State or Local building codes will not be used.

Note 2: Projects that have significant time delays between the award for design and the beginning of construction must be re-evaluated and corrected to comply with any new editions of criteria (including codes and standards) that have been published.

II.2.2 Existing Facilities

Existing facilities must meet the requirements of NFPA 101, *Life Safety Code*, for existing occupancies.

These requirements translate into the application of the following codes and standards:

1. International Building Code 2006 edition
2. NFPA 101 Life Safety Code 2006 edition
3. All NFC (NFPA) codes and standards as applicable, including NFPA 52 Vehicular Fuel Systems Code 2006 edition and NFPA 55 Standard for the Storage, Use, and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders, and Tanks 2005 edition.

In addition to the codes listed in the UFC the International Fire Code, International Fuel Gas Code and International Mechanical Code were reviewed because they contained provisions that dealt specifically with hydrogen safety. The 2006 editions (most recent) of the International codes were used in this review.

II.2.3 Summary of UFC Code Compliance Analysis

Based on the information submitted by the hydrogen supplier, the proposed hydrogen fueling operation would comply with the applicable code requirements as defined by Unified Facilities Criteria (UFC) (3-600-01 26 September 2006). Table 1. Codes and Standards for Bulk Hydrogen Storage Facilities and Indoor Hydrogen Dispensing lists codes and standards citations that would apply to the storage and dispensing operation. These citations were in effect during the pre-construction review period (May 2008). Since May 2008, several of these documents have been updated and NFPA hydrogen requirements have been consolidated into NFPA 2 Hydrogen Technologies Code.

The following list includes key code compliance areas an evaluation of the code compliance status for these areas.

Sprinkler protection. The hydrogen storage would be entirely outdoors. Therefore, the proposed process would not add any additional storage to the building. Therefore, no new sprinkler system capacity requirements would be triggered.

UFC requires the following for automatic sprinkler systems.

"6-1.1 Automatic Sprinkler Protection

Complete automatic sprinkler protection must be provided for buildings that include personnel housing and lodging. NFPA 13 or NFPA 13R, Sprinkler Systems in Residential Occupancies up to and Including Four Stories in Height, sprinkler systems are permitted when listed for the specific use."

The analysis is based on the assumption that the existing building complies with this requirement to provide automatic sprinkler system protection.

Ventilation. The size and number of openings in the building made it very difficult to measure volumetric flow rate through the building. Although no quantitative assessment has been made of the building ventilation, the site industrial hygienist has made qualitative assessments of the building ventilation. He felt the ventilation was adequate to allow for the dispersion of a hydrogen release if the large overhead ceiling fans that drive air downward were turned off.

In the event of a hydrogen release, the large overhead fans shall be turned off. This action should be incorporated into the standard operating procedures that define building operations.

Electrical. The proposed process meets the requirements of the National Electric Code® NFPA 70 as referenced in NFPA 52 and NFPA 55.

Life Safety Code. The proposed fueling system would not change the facilities life safety requirements or compliance status. The indoor fueling equipment is not in an egress path. The question was raised as to whether placing a hydrogen dispensing station indoors would obviate the path of egress closest to the dispenser. However, the dispenser is not located in the path of egress and therefore would not eliminate any existing egress paths.

Fire Alarm System. NFPA 72 requires that the alarm for the fueling system be tied into the existing system. This connection will be made before the system is operated. The fueling system will be shut down if the alarm is activated. The building should be evacuated as required in the plan required under IFC 2209.4 shown in the table of code requirements. The connection to the existing system must be coordinated between the system designer/installer and the hydrogen supplier.

Hydrogen Storage System Siting Requirements. Drawings of the H2Fueling Station Layout in the final design package for the outdoor drawings show that the system would meet the tabular requirements shown in 11.3.2.2 from NFPA 55 shown earlier. Note that this system would have to comply with both the separation distances for liquefied hydrogen storage systems and gaseous systems because the liquid hydrogen is being vaporized and stored as gaseous hydrogen before being dispensed into the forklift vehicles.

Additional recommendations. The following recommendations were made during the pre-construction plan review**.** To ensure that this system is installed correctly and is operated safely will require extensive coordination with site personnel. Although the system design material and supporting information would show compliance with code requirements as defined in UFC 3-600-1, this does not necessarily mean that the system will be installed as designed and that operational requirements will be met.

To ensure that the system is installed as designed and operated safely, it is recommended that a team be formed consisting of at least the Air Products project manager, the site facilities manager, and the site fire personnel that would perform at least the following functions:

Monitor the installation of the system

Monitor the pressure testing of the system after it is installed

Develop the required site emergency response and training plans

Document that the employees have been trained

State, in the emergency response plan, when the large overhead fans must be shut off to prevent any hydrogen release from dispersing

Document any incidents

And document when the system is not performing in the accepted performance range and take corrective action.

Table 1. Code and Standards Citations for Bulk Hydrogen Storage Facilities and Indoor Hydrogen Dispensing Operations list codes and standards that the project must comply with as a result of the UFC reference to the International Building Code (IBC) and the National Fire Codes (NFC). The IBC refers to the International Fire Code (IFC), International Mechanical Code (IMC) and International Fuel Gas Code (IFGC) that contain hydrogen specific requirements in the I codes.

Table 1. Codes and Standards Citations for Bulk Hydrogen Storage Facilities and Indoor Hydrogen Dispensing Operations.

Annual Inspections

CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association, 2005)

7.0 Maintenance and Repair

CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association, 2004)

9 Maintenance

International Fire Code (International Code Council, 2009)

406.2 Frequency

901.6.2 Records

907.2 Inspection, Testing, and Maintenance

2206.2.1.1 Inventory Control for Underground Tanks

3204.5.2 Corrosion Protection

3205.4 Filling and Dispensing

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.2.15 General System Requirements

Balance of Plant

Piping & Tubing

ASME B31.3, Process Piping (American Society of Mechanical Engineers, 2006)

F323.4(5) Specific Material Considerations-Metals

IX K305 Pipe

ASME B31.12, Hydrogen Piping and Pipelines

CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association, 2005)

3.1 General

3.2 Piping Materials

5.0 Installation

5.1 Piping Installation General

5.2 Piping Installation Above Ground Installation

5.3 Piping Installation Underground Installation

International Fire Code (International Code Council, 2009)

2201.1 Scope

2209.3.2.3 Indoors

2209.3.2.6 Canopy Tops

3501.1 Scope

International Fuel Gas Code (International Code Council, 2009)

101.2.1 Gaseous Hydrogen Systems

704 Piping, Use, and Handling

705 Testing of Hydrogen Piping Systems

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.8 Installation of Piping and Hoses

9.9 System Testing

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

11.2.3 Piping, Tubing, and Fittings

CGA H-3 Cryogenic Hydrogen Storage (Compressed Gas Association, 2006)

10.0 External piping

Pressure Relief

CGA S-1.3, PRD Standards Part 3 - Stationary Storage Containers for Compressed Gases (Compressed Gas Association, 2005)

5.3.2 Nonliquid Compressed Gases

International Fire Code (International Code Council, 2009)

2209.2.1 Approved Equipment

2209.5.4.2 Pressure Relief Devices

3003.3 Pressure Relief Devices

3203.2 Pressure Relief Devices

3203.3 Pressure Relief Vent Piping

3203.5.4 Physical Protection

3203.8 Service and Repair

3205.1.2.3.2 Shutoff Valves on Piping

International Fuel Gas Code (International Code Council, 2009)

703.3 Pressure Relief Devices

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

5.4 Pressure Relief Devices

5.6 Pressure Gauges

5.7 Pressure Regulators

9.6 Installation of Pressure Regulators

9.7 Installation of Pressure Gauges

14.6 Pressure Relief Devices

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

7.1.2.5 Pressure-Relief Devices

10.2.1 Pressure-Relief Devices

Valving & Fittings

ASME B31.3, Process Piping (American Society of Mechanical Engineers, 2006)

IX K306 Fittings, Bends, and Branch Connections

IX K307 Valves and Specialty Components

CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association, 2005)

3.3.2 Isolation Valves

3.3.3 Emergency Isolation Valves

3.3.4 Excess Flow Valves

3.3.5 Check Valves

3.3.7 Gasket and Sealing Materials

3.3.8 Additional Requirements

5.0 Installation

5.1 Installation General

International Fire Code (International Code Council, 2009)

2209.5.2 Emergency Shutoff Valves

2211.8.1.2.4 Grounding and bonding

2703.2.2 Piping, Tubing, Valves, and Fittings

2703.9.3 Protection from Vehicles

2703.10.1 Valve Protection

2705.1.10 Liquid Transfer

3003.6 Valve Protection

3005.3 Piping Systems

3005.4 Valves

3203.2.6 Shutoffs Between Pressure Relief Devices and Containers

3205.1.2 Piping Systems

3205.3.2 Emergency Shutoff Valves

3503.1.3 Emergency Shutoff

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

5.9 Valves

Venting and Other Equipment

CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association, 2004)

6.0 Vent System

6.2 Sizing

6.3 Design

6.4 Materials

6.5 Components

7 Installation

International Fire Code (International Code Council, 2009)

2209.5.4 Venting of Hydrogen Systems

2211.8.1.2 Atmospheric Venting of Hydrogen from Motor Vehicle Fuel Storage Containers

3003.16.8 Connections

3005.5 Venting

3203.3 Pressure Relief Vent Piping

3204.4.5 Venting of Underground Tanks

International Fuel Gas Code (International Code Council, 2009)

703.4 Venting

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

5.5 Vent Pipe Termination

9.3.3.3 Indoors

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

10.2.2 Pressure-Relief Devices

Canopy Tops

International Building Code (International Code Council, 2009)

406.5.2.1 Canopies use to support gaseous hydrogen systems

International Fire Code (International Code Council, 2009)

2209.3.2.6 Canopy Tops

2209.3.3 Canopies

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.3.2.3 Outdoors

Compressed Hydrogen Gas Storage

Equipment Location

International Fire Code (International Code Council, 2009)

2209.3 Location on Property

3503 General Requirements

3504 Storage

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.3 System Siting

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

10.3.2 Specific Requirements

General Safety Requirements

International Fire Code (International Code Council, 2009)

2209.5 Safety Precautions

2211.7 Repair Garages for Vehicles Fueled by Lighter-than-Air Fuels

2211.8 Defueling of Hydrogen from Motor Vehicle Fuel Storage Containers

3003 General Requirements

3503 General Requirements

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.2.3 Equipment Security and Vehicle Protection

9.2.4 Out of Service Bulk Storage

9.2.5 Equipment Security and Vehicle Protection

9.2.6 Cargo Transport Unloading

9.2.7 Control Device Icing

9.2.8 Vehicle Ignition Classification

9.2.9 Fueling Connection Leak Prevention

9.2.10 Compression and Processing Equipment

9.2.11 Reference to NFPA 37 for Compressor Installations

9.2.12 Electrical Classification for Compressors

9.2.13 Liquid Carryover Prevention

9.2.14 Detection for Dispensing Equipment

9.2.15 General System Requirements

9.2.16 General System Requirements

NFPA 55, Standard for Storage, Use and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers, Cylinders and Tanks (National Fire Protection Association, 2005)

7.1.4 Security

Storage Containers

CGA PS-20, Direct Burial of Gaseous Hydrogen Storage Tanks (Compressed Gas Association, 2006)

CGA PS-21, Adjacent Storage of Compressed Hydrogen and Other Flammable Gases (Compressed Gas Association, 2005)

International Fire Code (International Code Council, 2009)

2703.2.1 Design and Construction of Containers, Cylinders, and Tanks

3003.2 Design and Construction

3503.1.2 Storage Containers

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

5.3 Design and Construction of Containers

Compression Systems and Equipment

International Fire Code (International Code Council, 2009)

2209.2 Equipment

2209.3 Location on Property

2209.5.3.1 System Requirements

2209.5.4.2.1 Minimum Rate of Discharge

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.2.7 Control Device Icing

9.2.8 Vehicle Ignition Classification

9.2.9 Fueling Connection Leak Prevention

9.2.10 Compression and Processing Equipment

9.2.11 Reference to NFPA 37 for Compressor Installations

9.2.12 Electrical Classification for Compressors

9.2.13 Liquid Carryover Prevention

9.2.14 Detection for Dispensing Equipment

9.3.1 General

14.8 Stationary Pumps and Compressors

Design

Barrier Walls

International Fire Code (International Code Council, 2009)

2209.3.1.1 Barrier Wall Construction – Gaseous Hydrogen

Equipment

International Fire Code (International Code Council, 2009)

2209.2 Equipment

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.2 General System Requirements

Fuel Stations

International Fire Code (International Code Council, 2009)

35 Flammable Gases

2209.1 General

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

7.3 Motor Fuel Dispensing Facilities

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.3 System Siting

14.2 Facility Design

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

7.1.6 Separation from Hazardous Conditions

Weather Protection

International Fire Code (International Code Council, 2009)

2209.3.2.2 Weather Protection

2704.13 Weather Protection

Dispensing

Electrical Equipment

International Fire Code (International Code Council, 2009)

2201.5 Electrical

2205.4 Sources of Ignition

2209.2.3 Electrical Equipment

2211.3.1 Equipment

2211.8.1.2.4 Grounding and bonding

2703.9.4 Electrical Wiring and Equipment

3003.8 Wiring and Equipment

3003.16.14 Classified Areas

3203.7 Electrical Wiring and Equipment

3503.1.5.1 Bonding of Electrically Conductive Materials and Equipment

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

6.7 Emergency Electrical Disconnects

8 Electrical Installations

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.11 Installation of Electrical Equipment

9.12 Stray or Impressed Currents and Bonding

Fuel Lines

CGA G-5.4, Standard for Hydrogen Piping Systems at Consumer Locations (Compressed Gas Association, 2005)

3.0 Piping System Criteria

International Fire Code (International Code Council, 2009)

2201 Scope

2209.3.2.3 Indoors

2209.3.2.6 Canopy Tops

3501.1 Scope

International Fuel Gas Code (International Code Council, 2009)

101.2.1 Gaseous Hydrogen Systems

704 Piping, Use, and Handling

705 Testing of Hydrogen Piping Systems

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

5.8 Fuel Lines

Gaseous Dispensers

International Fire Code (International Code Council, 2009)

2209.2 Equipment

2209.3 Location on Property

2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.2 General System Requirements

9.3 System Siting

Hoses and Connectors

International Fire Code (International Code Council, 2009)

2209.2 Equipment

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

5.10 Hose and Hose Connections

Liquid Dispensers

International Fire Code (International Code Council, 2009)

2206.7.4 Dispenser Emergency Valve

2206.7.5 Dispenser Hose

2206.7.6 Fuel Delivery Nozzles

2209.2 Equipment

2209.3 Location on Property

2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

6.3 Requirements for Dispensing Devices

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

14 Liquid Hydrogen Fueling Facilities

Vehicle Connectors

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

5.11 Vehicle Fueling Connection

SAE J2600, Compressed Hydrogen Surface Vehicle Refueling Connection Devices (Society of Automotive Engineers, 2002)

Dispensing, Operations, and Maintenance Safety

Gaseous Hydrogen

CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association, 2004)

9 Maintenance

International Fire Code (International Code Council, 2009)

2204 Dispensing Operations

2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

9.2.2 Tank Filling and Bulk Delivery

9.4 Operating Requirements for Attended Self-Service Motor Fuel Dispensing Facilities

9.5 Operating Requirements for Unattended Self-Service Motor Fuel Dispensing Facilities

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.13 System Operation

9.14 Fire Protection

9.15 Maintenance System

Liquid Hydrogen

CGA G-5.5, Hydrogen Vent Systems (Compressed Gas Association, 2004)

9 Maintenance

International Fire Code (International Code Council, 2009)

2204 Dispensing Operations

2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

9.2.2 Tank Filling and Bulk Delivery

9.4 Operating Requirements for Attended Self-Service Motor Fuel Dispensing Facilities

9.5 Operating Requirements for Unattended Self-Service Motor Fuel Dispensing Facilities

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

14.4.6 Liquid Hydrogen Vehicle Dispensing Systems

14.4.9 Liquid Hydrogen Vehicle Dispensing Systems

14.4.10 Liquid Hydrogen Vehicle Dispensing Systems

14.4.11 Liquid Hydrogen Vehicle Dispensing Systems

14.13 Maintenance

Fire Safety

Construction

International Fire Code (International Code Council, 2009)

911 Explosion Control

2209.5 Safety Precautions

International Fuel Gas Code (International Code Council, 2009)

706.3 Outdoor Gaseous Hydrogen Systems

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.12 Stray or Impressed Currents and Bonding

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

7.1.6 Separation from Hazardous Conditions

Equipment

International Fire Code (International Code Council, 2009)

404 Fire Safety and Evacuation Plan

406 Employee Training and Response Procedures

407 Hazard Communication

906 Portable Fire Extinguishers

907 Fire Alarm and Detection Systems

2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities

2209.5 Safety Precautions

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.2.3 Equipment Security and Vehicle Protection

9.2.4 Out of Service Bulk Storage

9.2.5 Equipment Security and Vehicle Protection

9.2.15 General System Requirements

9.3.3 Indoors

9.14 Fire Protection

14.2.4 Indoor Fueling

14.4.3 Liquid Hydrogen Vehicle Dispensing Systems

Signage

International Fire Code (International Code Council, 2009)

2204.3.5 Emergency Procedures

2209.5.2.1 Identification

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.3.3.12 Warning Signs

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

6.12 Hazard Identification Signs

10.2.4 Marking

11.3.1.4 General

Liquid Hydrogen Storage

Equipment Location

International Fire Code (International Code Council, 2009)

2209.3 Location on Property

3203.5.4 Physical Protection

3203.6 Separation from Hazardous Conditions

3204.3.1.1 Location

3204.4.2 Location

3504 Storage

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

11.3.1 General

11.3.2 Specific Requirements

General Safety Requirements

International Fire Code (International Code Council, 2009)

2209.5 Safety Precautions

2211.7 Repair Garages for Vehicles Fueled by Lighter-than-Air Fuels

2211.8 Defueling of Hydrogen from Motor Vehicle Fuel Storage Containers

3003 General Requirements

3203 General Safety Requirements

3503 General Requirements

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

14.2 Facility Design

Storage Containers

International Fire Code (International Code Council, 2009)

2703.2 Systems, Equipment, and Processes

3203.1 Containers

3203.5 Security

3203.6 Separation from Hazardous Conditions

3204.3.1 Stationary Containers

3204.4 Underground Tanks

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

5.3 Design and Construction of Containers

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

11.3.2 Specific Requirements

11.4.2 Underground Tanks

CGA H-3 Cryogenic Hydrogen Storage (Compressed Gas Association, 2006)

6.0 Tank design and manufacturing criteria

7.0 Inner vessel

8.0 Outer jacket

On-Site Hydrogen Production

International Fire Code (International Code Council, 2009)

2209.3.1 Separation from Outdoor Exposure Hazards

International Fuel Gas Code (International Code Council, 2009)

703.1 General Requirements

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

5.2 System Approvals

Operation Approvals

Dispensing

International Fire Code (International Code Council, 2009)

2204.2 Attended Self-Service Motor Fuel-Dispensing Facilities

2204.3 Unattended Self-Service Motor Fuel-Dispensing Facilities

2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

6.2 General Requirements

6.3 Requirements for Dispensing Devices

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

14.4.1 Liquid Hydrogen Vehicle Dispensing Systems

14.4.2 Liquid Hydrogen Vehicle Dispensing Systems

14.4.3 Liquid Hydrogen Vehicle Dispensing Systems

14.4.11 Liquid Hydrogen Vehicle Dispensing Systems

Fire And Emergency Planning

International Fire Code (International Code Council, 2009)

404 Fire Safety and Evacuation Plan

406 Employee Training and Response Procedures

407 Hazard Communication

906 Portable Fire Extinguishers

907 Fire Alarm and Detection Systems

2209.3.2.6.2 Fire-Extinguishing Systems

2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities

2209.5.1 Protection from Vehicles

2209.5.2 Emergency Shutoff Valves

2209.5.3 Emergency Shutdown Controls

2209.5.4 Venting of Hydrogen Systems

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

7.3.5 Fixed Fire Protection

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.2.16 General System Requirements

9.10.5 Installation of Emergency Shutdown Equipment

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

4.1 Permits

4.2 Emergency Plan

7.1.6 Separation from Hazardous Conditions

Fuel Delivery

International Fire Code (International Code Council, 2009)

105.6.8 Compressed Gases

105.6.10 Cryogenic Fluids

2205.1 Tank Filling Operation for Class I, II, or IIIA Liquids

3205.4 Filling and Dispensing

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

6.3.7 Requirements for Dispensing Devices

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.2.3 Equipment Security and Vehicle Protection

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

10.3 Location of Gaseous Hydrogen Systems

Ignition Control

International Fire Code (International Code Council, 2009)

2209.3.2.3.3 Ignition Source Control

3503.1.4 Ignition Source Control

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

4.8 Ignition Source Controls

7.6.3 Ignition Source Control

Personnel Issues and Training

International Fire Code (International Code Council, 2009)

406 Employee Training and Response Procedures

2209.4 Dispensing into Motor Vehicles at Self-Service Hydrogen Motor Fuel-Dispensing Facilities

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

9.4 Operating Requirements for Attended Self-Service Motor Fuel Dispensing Facilities

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

4.6 Personnel Training

4.7 Fire Department Liaison

Signage

International Fire Code (International Code Council, 2009)

2204.3.5 Emergency Procedures

2209.3.2.3.2 Smoking

2209.3.2.6.3 Signage

2209.5.2.1 Identification

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.3.3.12 Warning Signs

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

4.9 Signs

Vehicle Access

International Fire Code (International Code Council, 2009)

105.6.8 Compressed Gases

105.6.10 Cryogenic Fluids

105.6.39 Repair Garages and Motor Fuel-Dispensing Facilities

404.3.2 Fire Safety Plans

3205.4 Filling and Dispensing

NFPA 30A, Code for Motor Fuel Dispensing Facilities and Repair Garages (National Fire Protection Association, 2003)

6.3.7 Requirements for Dispensing Devices

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.2.3 Equipment Security and Vehicle Protection

14.2.1.6 General

14.4.2 Liquid Hydrogen Vehicle Dispensing Systems

14.4.5 Liquid Hydrogen Vehicle Dispensing Systems

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

10.3 Location of Gaseous Hydrogen Systems

Setbacks and Footprints

Liquid Systems

International Fire Code (International Code Council, 2009)

2209.3.1 Separation from Outdoor Exposure Hazards

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

14.2.2 Siting

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

11.3.2.1 Specific Requirements

11.3.2.2 Specific Requirements

Outdoor Gaseous Systems

International Fire Code (International Code Council, 2009)

2209.3.1 Separation from Outdoor Exposure Hazards

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

9.3.1.3 General

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

10.3.2.1 Specific Requirements

10.3.2.2 Minimum Distance

Transportation

Compressed Hydrogen Gas

CGA P-1, Safe Handling of Compressed Gases in Containers (Compressed Gas Association, 2006)

4.1 Transportation Regulating Authorities

4.2 Container Regulations

4.3 Container Filling Regulations

4.4 Regulating Authorities of Employee Safety and Health

6.2 Flammable Gases

International Fire Code (International Code Council, 2009)

2705 Use, Dispensing, and Handling

3005.7 Transfer

3505 Use

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

4 General Requirements

7.3.1.10 Use and Handling

Liquid Hydrogen

CGA P-12, Safe Handling of Cryogenic Liquids (Compressed Gas Association, 2005)

5.5.4 Additional Safety Practices for Liquid Hydrogen

6.4 Hydrogen Fires

7.9 Handling Considerations for Hydrogen and Helium Transfer

International Fire Code (International Code Council, 2009)

2705 Use Dispensing and Handling

3201.1 Scope

3203.6.1.1 Point-of-Fill Connections

3205.4.2 Vehicle Loading and Unloading Areas

NFPA 52, Vehicular Gaseous Fuel Systems Code (National Fire Protection Association, 2010)

14.3 Cargo Transport Unloading

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

4 General Requirements

8.3.5 Overfilling

8.13.1.2 Attended Delivery

8.13.10.3 Filling and Dispensing

Natural Gas

ASME B31.8, Gas Transmission and Distribution Systems (American Society of Mechanical Engineers, 2003)

Vaporizers

International Fire Code (International Code Council, 2009)

2209.2 Equipment

2209.3 Location on Property

3203.1.3 Foundations and Supports

3203.2.2 Vessels or Equipment Other than Containers

3203.5.3 Securing of Vaporizers

International Fuel Gas Code (International Code Council, 2009)

708 Design of Liquefied Hydrogen Systems Associated with Hydrogen Vaporization Operations

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

11.2.5 Liquefied Hydrogen Vaporizers

II.3 Recommendations on any compliance issues

Although the site visit conducted by NREL personnel brought to light many operational issues, most of them logistical concerns as opposed to safety concerns, there was no information that indicated that the site was out of compliance with the UFC or other safety requirements.

Recommendations on how the findings could be applied to other projects

There were several issues that became apparent during the site inspection that would potentially improve operations and safety. These issues include the following:

1. As a part of the project design phase, define forklift operating schedules and demands and match forklift performance to forklift operational demands to the extent possible.
2. Locate forklift fueling equipment to reduce forklift downtime during shifts
3. Design forklift exhaust and other operating characteristics to accommodate operator safety and comfort
4. Review hydrogen dispensing and storage operations history with site safety personnel during the project design phase to address safety concerns

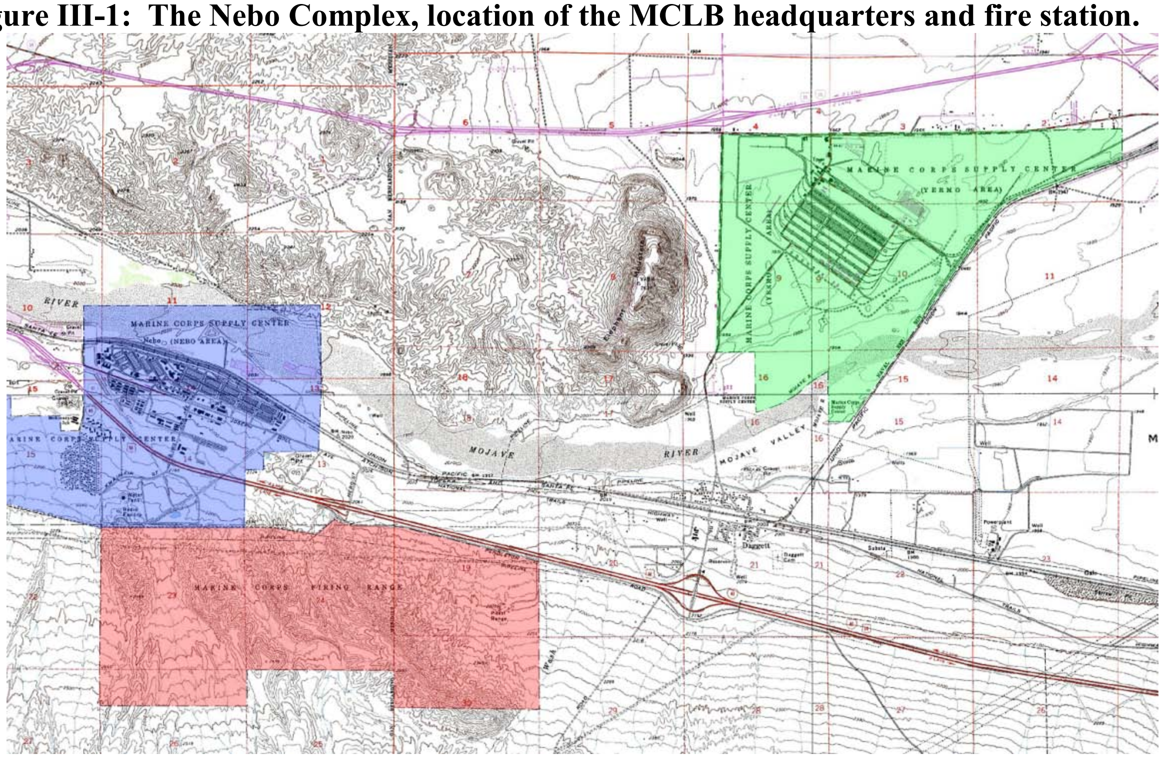
III.1 The Marine Corps Logistics Base Barstow, CA

The Marine Corps Logistic Base at Barstow, CA was selected for deployment of a stationary hydrogen fuel cell system to provide backup power. The MCLB is located outside of Barstow, CA. This region of California is desert-like and sparsely populated. The base is located on Interstate 40, 3 1/2 miles east of the city of Barstow. The MCLB is a vital link in the logistics complex that provides the weapons systems, equipment and special logistics essential to supporting the assigned missions of the Fleet Marine Forces. To accomplish this, Barstow is positioned in a strategic geographical location. Barstow lies at the junction of three major highways systems of I-15, I-40, and Highway 58, and is the located at the hub of all west coast rail traffic for the Burlington Northern/Santa Fe and the Union Pacific railroads. It is in the immediate proximity of the regional air, Daggett Airport. Barstow, CA is within 150 miles of the two major seaports of Los Angeles and San Diego. Because of its arid desert climate, equipment can be stored outdoors with minimal maintenance required.

III.1 The MCLB Proposed Stationary Fuel Cell Backup Power Deployment

The MCLB has several groups and facilities that support the base's mission, including the Nebo Annex. The Nebo Annex (shown in Figure III-1) encompasses 1,879 acres (8 km^2) and functions as base headquarters and is the main facility for administration, storage, recreational activities, shopping, and housing functions. The base fire station is also located within the Nebo Annex.

Figure III-1: The Nebo Complex, location of the MCLB headquarters and fire station.



The MCLB plans call for the installation of a stationary fuel cell to provide backup power at the fire station located on the Nebo Complex. The power requirement for this facility is estimated to be 20 kW. The MCLB Barstow currently uses diesel generators for backup power; this includes the backup power system for the MCLB fire station. The diesel generators require significant maintenance and are now required to obtain a permit from the South Coast Air Quality Management District in order to operate due to their emissions. The MLCB Barstow wishes to use fuel cell technology for power backup systems due to its high reliability, low maintenance, and clean operation. The DOE is assisting the MCLB in this project by providing some of the funding through an interagency agreement. This information was conveyed to NREL by DOE personnel working on the project. This partnership with DOE is part of an effort to advance the use of stationary fuel cells.

An overview of site operations and a review of the underlying codes and standards as they pertain to the deployment of hydrogen-powered fuel cells are presented below.

III.1.1 Site Visit and Review of the MCLB Site Operations

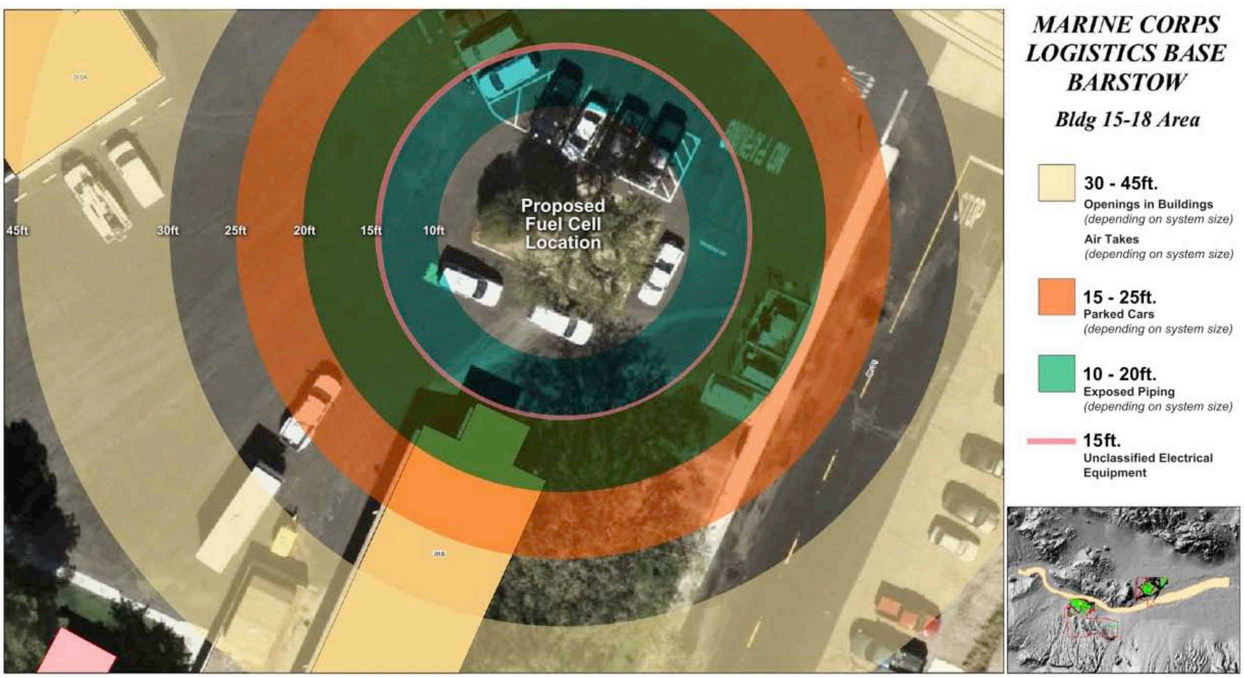
On April 27, 2010, Carl Rivkin from NREL Codes and Standards Group visited the MCLB site. Mr. Rivkin met with Sharon Ott from the MCLB Public Works Division. Installation and approval of the stationary power fuel cell power system was not yet completed at the time of the NREL site visit, nevertheless the site operations were reviewed and NREL assisted in identifying pertinent code requirements, which would facilitate permitting. These documents are identified in Table 3 Codes and Standards Citations for Stationary Fuel Cells.

III.1.2 Incidental Issues/ Site Permitting Issues

This project is located at a Department of Defense facility and thus is not subject to the permitting requirements of the local enforcing authorities, which are the City of Barstow, CA and Fresno County. Therefore, the administrative process for permitting is potentially less complex than with facilities that might require permits from multiple Authorities Having Jurisdiction (AHJs) within the jurisdiction that address different aspects of the project. As discussed below, DOD facilities are subject to the Unified Facilities Criteria (UFC) 3-600-01 Fire Protection Engineering for Facilities. The UFC document requires compliance with the International Building Code and all National Fire Protection Association documents collectively referred to as the National Fire Code (NFC). UFC 3-600-01 refers to NFPA 853 Standard for Installation of Stationary Fuel Cell Power Systems 2009 edition, which is the primary installation document for stationary fuel cells. In turn, NFPA 853 refers NFPA 55 Code for Compressed Gases and Cryogenic Fluids 2010 edition (NFPA 55).

During the site visit, NREL personnel reviewed the proposed fuel cell site outside of the base fire department. One of the most difficult code compliance issues with this project was siting the bulk gaseous hydrogen storage system for the fuel cell. Because the location for the fuel cell was determined by its intended application, backup power for the fire station, the storage system location was required to be proximate to the fire station. Despite the base being located in a sparsely populated area and the building density on the base being relatively low, the hydrogen storage was limited to an area where there were siting restrictions. On other projects in other locations, an up front evaluation of potential locations for siting the hydrogen storage system could make the project installation easier. NFPA 55 provides guidance on setback distances for hydrogen storage facilities. NFPA provides prescriptive tables that provide setback distances of various *exposures* (see Table 10.3.2.2.1 in NFPA 55, shown as Table 2). These prescriptive set back distances are reproduced in Table III-1 of this report. Figure III-2 shows the location of the storage system and key separation distances proscribed by NFPA 55. Because of the restriction placed on the hydrogen storage by the NFPA prescriptive tables for setback distances, there were few locations where the storage system could be located. For example the most restrictive setback distances for siting this fuel cell as per NFPA 52 are likely as follows (assuming this will be a system that falls into the 250 psig to 3000 psig range):

1. Distance to lot lines -45 feet (use equation a or b, Table III-1)
2. Openings (operable) in buildings – 45 feet (use equation a, Table III-1)
3. Air intakes – 45 feet (use equation a, Table III-1)
4. Parked cars – 25 feet (use equation c, Table III-1)



The 2010 edition of NFPA 55 provides an alternative method to determine the separation distances for siting a bulk gaseous hydrogen storage system. This alternative *computational method* is based on calculating distances using pipe diameters (see Table 10.3.2.2.1.1 in NFPA 55). These computational set back distances are reproduced in Table III-2 of this report. The computational method is guided by pipe diameter. The computational method may results in less restrictive setback distances. Assuming a ½ inch pipe diameter the following distances are calculated:

1. Distance to lot lines - feet (use equation a or b, Table III-2) Approximately 19 feet
2. Openings (operable) in buildings – feet (use equation a, Table III-2) Approximately 31 feet
3. Air intakes – feet (use equation a, Table III-2) Approximately 31 feet
4. Parked cars – feet (use equation c, Table III-2) Approximately 14 feet

The computational method of determining separation distances results in smaller separation distances than those shown in the prescriptive table. This outcome is based on the pipe diameter selected. In other situations the computed distances could be greater than those shown in the prescriptive tables. It is recommended that an analysis of the setback distances based on the computational methods provided in NFPA 55 should be performed as part of the siting evaluation for any project where site space issues may exist.

Table 2. Separation Distances for Bulk Gaseous Hydrogen Storage Systems from Various Exposures (Table 10.3.2.2.1 (b) from the 2010 edition of NFPA 55 Gaseous and Cryogenic Fluids Code)

Exposure	Total Gaseous Hydrogen Storage			
	>103.4 to ≤1724 kPa 52.50 mm ID (m)	>1724 to ≤ 20,684 kPa 18.97 mm ID (m)	>20,684 to ≤51,711 kPa 7.92 mm ID (m)	>51,711 to ≤103,421 kPa 7.16 mm ID (m)
(1) Lot lines[greater of a or b]	12.14	14.00	8.75	10.38
(2) Exposed persons other than those involved in servicing of the system[c]	5.94	7.02	4.13	5.05
(3) Buildings and structures				
Combustible construction[d]	5.04	5.82	3.64	5.6
Noncombustible non-fire-rated construction[e]	5.04	5.82	3.64	3.64
Fire-rated construction with a fire resistance rating of not less than 2 hours[f]	1.5	1.5	1.5	1.5
(4) Openings in buildings of fire-rated or non-fire-rated construction (doors, windows, and penetrations)				
Openable[a] Fire-rated or non-fire-rated	12.14	14.00	8.75	10.38
Unopenable[d] Fire-rated or non-fire-rated	5.04	5.82	3.64	4.31
(5) Air intakes (HVAC, compressors, other)[a]	12.14	14.00	8.75	10.38
(6) Fire barrier walls or structures used to shield the bulk system from exposures[f]	1.5	1.5	1.5	1.5
(7) Unclassified electrical equipment[g]	4.7	4.7	4.7	4.7
(8) Utilities (overhead), including electric power, building services, or hazardous materials piping[d]	5.04	5.82	3.64	4.31
(9) Ignition sources such as open flames and welding[a]	12.14	14.00	8.75	10.38
(10) Parked cars[c]	5.94	7.02	4.13	5.05

(continues)

Exposure	Total Gaseous Hydrogen Storage >103.4 to ≤1724 kPa 52.50 mm ID (m)	>1724 to ≤ 20,684 kPa 18.97 mm ID (m)	>20,684 to ≤51,711 kPa 7.92 mm ID (m)	>51,711 to ≤103,421 kPa 7.16 mm ID (m)
(1) Lot lines[greater of a or b]	12.14	14.00	8.75	10.38
(2) Exposed persons other than those involved in servicing of the system[c]	5.94	7.02	4.13	5.05
(3) Buildings and structures				
Combustible construction[d]	5.04	5.82	3.64	5.6
Noncombustible non-fire-rated construction[e]	5.04	5.82	3.64	3.64
Fire-rated construction with a fire resistance rating of not less than 2 hours[f]	1.5	1.5	1.5	1.5
(4) Openings in buildings of fire-rated or non-fire-rated construction (doors, windows, and penetrations)				
Openable[a] Fire-rated or non-fire-rated	12.14	14.00	8.75	10.38
Unopenable[d] Fire-rated or non-fire-rated	5.04	5.82	3.64	4.31
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(8) Utilities (overhead), including electric power, building services, or hazardous materials piping[d]	5.04	5.82	3.64	4.31
(9) Ignition sources such as open flames and welding[a]	12.14	14.00	8.75	10.38
(10) Parked cars[c]	5.94	7.02	4.13	5.05

(continues)

Table 3-2.Computional method based on pipe diameter for determination of separation Distances for Bulk Gaseous Hydrogen Storage Systems from Various Exposures (Table 10.3.2.1.1 .1(b) from the 2010 edition of NFPA 55 Gaseous and Cryogenic Fluids Code)

Notes*	>15 to ≤250 psi (>103.4 to ≤1724 kPa)	>250 to ≤3000 psi (>1724 to ≤ 20,684 kPa)	>3000 to ≤7500 psi (>20,684 ≤ 51,711 kPa)	>7500 to ≤15,000 psi (>51,711 ≤ 103,421 kPa)
(a)	$D_a = 0.23179d^{0.99931}$	$D_a = 0.73903d^{0.99962}$	$D_a = 1.1062d^{0.99969}$	$D_a = 1.4507d^{0.9996}$
(b)	$D_b = 0.091137d^{1.1303} + e^{-0.084081d}(0.087694d^{0.72681} - 0.091137d^{1.1303})$	$D_b = 0.36599d^{1.1152} + e^{-0.10771d}(0.1885d^{1.2531} - 0.36599d^{1.1152})$	$D_b = 0.60173d^{1.1063} + e^{-0.36516d}(-0.00002521d^{5.6078} - 0.60173d^{1.1063})$	$D_b = 0.84053d^{1.1023} + e^{-0.40365d}(-0.000043007d^{5.7146} - 0.84053d^{1.1023})$
(c)	$D_c = 0.075952d^{1.1022} + e^{-0.087589d}(0.076814d^{0.83088} - 0.075952d^{1.1022})$	$D_c = 0.2889d^{1.092} + e^{-0.10392d}(0.18705d^{1.1795} - 0.2889d^{1.092})$	$D_c = 0.45889d^{1.0887} + e^{-0.46723d}(-0.000027772d^{5.8841} - 0.45889d^{1.0887})$	$D_c = 0.6324d^{1.0859} + e^{-0.52477d}(-0.000086234d^{5.8213} - 0.6324d^{1.0859})$
(d)	$D_d = 0.096359d^{0.99928}$	$D_d = 0.3072d^{0.99962}$	$D_d = 0.45967d^{0.99971}$	$D_d = 0.60297d^{0.99966}$
(e)	$D_e = 0.096359d^{0.99928}$	$D_e = 0.3072d^{0.99962}$	$D_e = 0.45967d^{0.99971}$	$D_e = 0.60297d^{0.99966}$

Notes:

(1) Use of this table assumes a leak diameter of 3 percent of the pipe flow area or internal diameter where d = inside diameter (ID) of pipe or tube expressed in millimeters (mm), and $D_{a,b,c,d,\ or\ e}$ = separation distance in meters (m).

(2) All pressures are gauge pressures.

*Notes are from Table 10.3.2.2.1(a) and Table 10.3.2.2.1(b) as follows:

(a) Unignited jet concentration decay distance to 4 percent mole fraction (volume fraction) hydrogen

(b) D_{rad} – radiation heat flux level of 500 Btu/hr·ft^2 (1577 W/m^2)

(c) D_{rad} for heat flux level of 1500 Btu/hr·ft^2 (4732 W/m^2) exposure to employees for a maximum of 3 minutes

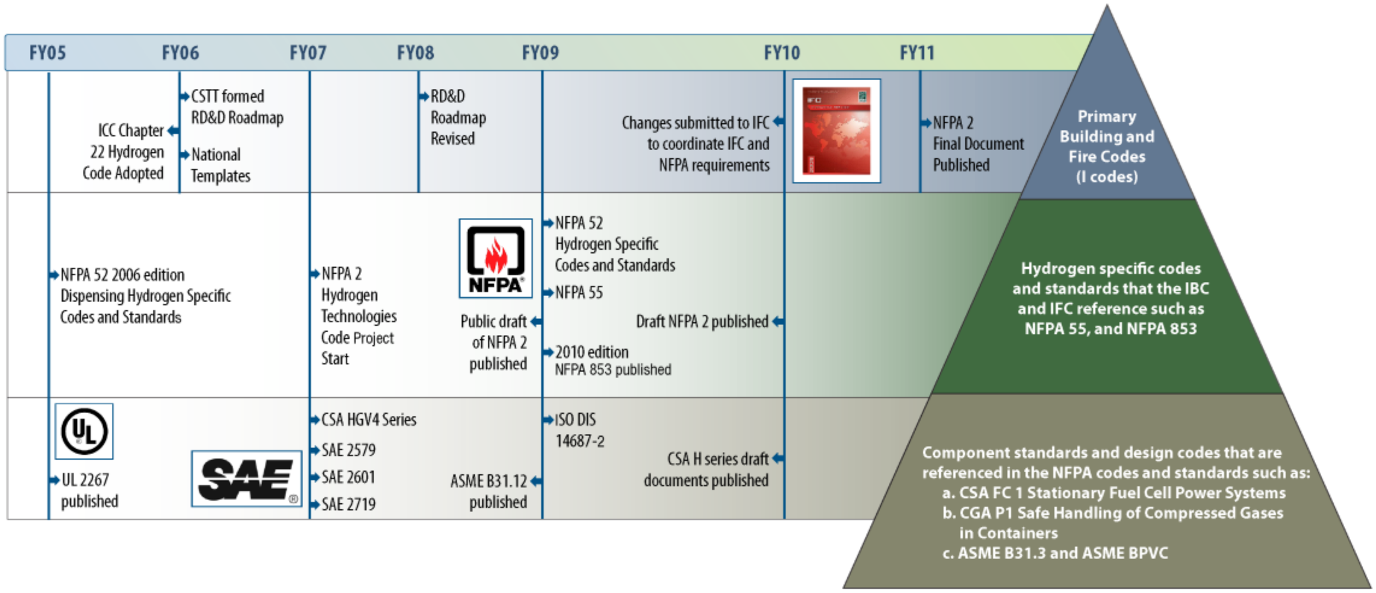
(d) The greater of D_{rad} for combustible heat flux level of 6340 Btu/hr·ft^2 (20,000 W/m^2) or the visible flame length

(e) The greater of D_{rad} for noncombustible equipment heat flux level of 8000 Btu/hr·ft^2 (25,237 W/m^2) or the visible flame length

III.2 Comprehensive codes and standards evaluation

The codes and standards that apply to the installation and operation of stationary fuel cells are relatively mature and well defined. The basic code structure is shown in Figure III-2. The pyramid in Figure III-2 shows that the regulatory chain starts with a jurisdiction's adoption of a building code. In this case the building code is first referred to in Unified Facilities Criteria (UFC) 3-600-01 Fire Protection Engineering for Facilities document that DoD facilities are subject to. The UFC document requires compliance with the International Building Code and all National Fire Protection Association documents collectively referred to as the National Fire Code (NFC).

Figure 2. Codes and Standards Hierarchy and Progress



The primary installation document for stationary fuel cells is NFPA 853 Standard for Installation of Stationary Fuel Cell Power Systems 2009 edition. This document is referred to in the Unified Facilities Criteria (UFC) 3-600-01 Fire Protection Engineering for Facilities document. This document sets requirements for the installation of PEM hydrogen fuel cells as well as other types of fuel cells. NFPA 853 refers to CSA FC 1 for the design of the fuel cell. NFPA 853 refers to NFPA 55 Code for Compressed Gases and Cryogenic Fluids for the hydrogen storage system requirements. NFPA 55 contains the table of separation, Table 1 distances for bulk gaseous hydrogen storage systems that may present difficulties for siting systems in very space restricted locations. Note that the separation distance requirements that are found in NFPA 55 have also been extracted into NFPA 2 Hydrogen Technologies Code. The requirements of FC1 are not explored in this report because this analysis is directed at the requirements for siting the fuel cell. At the time of the site visit the fuel cell had not been selected and therefore could not be reviewed for compliance with FC 1.

One of the most difficult code compliance issues with this project was siting the bulk gaseous hydrogen storage system for the fuel cell. Because the location for the fuel cell was determined by its intended application, backup power for the fire station, the storage system location was restricted to be proximate to the fire station. Despite the base being located in a sparsely populated area and the building density on the base being relatively low, the hydrogen storage was limited to an area where there were siting restrictions. On other projects in other locations, an up front evaluation of potential locations for siting the hydrogen storage system could make the project installation easier.

The citations include references to several key documents such as CSA America FC 1 -2004 Stationary Fuel cell Power Systems, NFPA 853 Standard for the Installation of Stationary Fuel Cell Power Systems, and NFPA 55 Code for Compressed gases and Cryogenic Fluids. These three documents address the design and performance of the fuel cell, (F/C 1), the installation of the fuel cell (NFPA 853), and the storage of the hydrogen to power the fuel cell (NFPA 55). The requirements that are in NFPA 55 and NFPA 853 have also been extracted into NFPA 2 Hydrogen technologies Code. There are also citations referenced from the International Building Code (IBC), the International Fire Code (IFC) and International Fuel Gas Code (IFGC) and the International Mechanical Code (IMC) that set general system safety requirements system construction, material storage, ventilation, and operation. The IFC addresses areas such as training and incident planning and the Maximum Allowable Quantities (MAQs) for storing hydrogen. NFPA 55 includes the MAQ requirements for indoor storage (it does not conflict with the IFC) and also contains requirements for bulk outdoor hydrogen storage systems. The IMC sets requirements for exhaust systems for enclosed installations, and the IFGC sets requirements for installation and testing of hydrogen piping systems.

The F/C 1 sets detailed system design requirements that address system performance and selection of system materials. The requirements cover general construction and performance, indoor installations, and direct vent fuel cells. There are performance testing requirements for these three categories of fuel cells. NFPA 853 sets system installation requirements that define where systems can be located. These locations include rooftop installations. NFPA 853 also addresses system fire protection requirements in detail.

There are also electrical safety requirements found in NFPA 70. The electrical requirements found in Article 692 address safe wiring, system grounding, and connection to other circuits.

Comprehensive codes and standards evaluation including any applicable local ordinances

Table 3: Code and Standard citations for Stationary Fuel Cell Applications

Codes and Standards Citations for Stationary Fuel Cell Applications
Construction Approval
NFPA 70, National Electric Code (National Fire Protection Association, 2008)
Article 692
ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association, 2004)
1.2 Power Systems Design
1.3 General Design Requirements
1.3.2 Protection from Environmental Conditions
1.3.3 Electrical Safety
1.3.5 Steam Backflow
1.3.6 FC System Purging
1.3.7 Safe Handling During Moving

1.3.8 Shock and Vibration Protection
1.3.9 Requirements for Not-Listed Equipment
1.3.11 Temperature Limits
1.4 Materials
1.5 General Construction and Assembly
1.6 Enclosures and Associated Construction
1.8.1 Metallic Piping
1.9 Drain, Venting and Ventilation Exhaust Systems
1.12.1 Manual Valves
1.12.2 Automatic Valves
1.12.3 Pressure Regulators
1.15 Electrical Equipment and Wiring
1.19.1 Materials for Markings
1.19.2 FC Labeling Requirements
1.19.4 - 1.19.7 Electrical Diagrams

International Building Code (International Code Council, 2009)

307.1.1 Maximum Allowable Quantities
414.1 General
414.2 Control Areas
414.4 Hazardous Materials Systems
414.6 Outdoor Storage, Dispensing, and Use
907 Fire Alarms and Detection Systems
1609 Wind Loads
1612 Flood Loads
1805 Footings and Foundation

International Fire Code (International Code Council, 2009)

401 General Emergency Planning and Preparedness
406 Employee Training and Response Procedures
2703.1 Hazardous Materials
2703.1.1 Maximum Allowable Quantities per Control Area
2703.1.3 Quantities Not Exceeding the Maximum Allowable Quantity per Control Area
2703.1.4 Quantities Exceeding the Maximum Allowable Quantity per Control Area
2703.2 Systems, Equipment, and Processes
2703.2.1 Design and Construction of Containers, Cylinders, and Tanks
2703.2.2 Piping, Tubing, Valves, and Fittings
2703.2.3 Equipment, Machinery, and Alarms
2703.2.4 Installation of Tanks
2703.2.5 Empty Containers and Tanks
2703.2.8 Seismic Protection
2703.2.9 Testing
2703.3 Release of Hazardous Materials
2703.4 Material Safety Data Sheets
2703.8 Construction Requirements

2703.8.1 Buildings
2703.8.2 Required Detached Buildings
2703.8.3 Control Areas
2703.8.4 Gas Rooms
2703.8.5 Exhausted Enclosures
2703.8.6 Gas Cabinets
2703.8.7 Hazardous Materials Storage Cabinets
2703.9 General Safety Precautions
2703.9.1 Personnel Training and Written Procedures
2703.9.1.1 Fire Department Liaison
2703.9.2 Security
2703.9.3 Protection from Stationary fuel cell applications
2703.9.4 Electrical Wiring and Equipment
2703.9.5 Static Accumulation
2703.9.6 Protection from Light
2703.9.7 Shock Padding
2703.9.8 Separations of Incompatible Materials
2703.9.9 Shelf Storage
2703.12 Outdoor Control Areas
2704 Storage
2705 Use, Dispensing, and Handling
3003.1 Containers, Cylinders, and Tanks
3003.2 Design and Construction
3003.3 Pressure Relief Devices
3003.4 Gas Marking
3003.4.1 Stationary Compressed Gas Containers, Cylinders, and Tanks
3003.4.2 Portable Containers, Cylinders, and Tanks
3003.4.3 Piping Systems
3003.5 Security
3003.6 Valve Protection
3003.6.1 Compressed Gas Container, Cylinder, or Tank Protective Caps or Collars
3003.7 Separations from Hazards
3003.8 Wiring and Equipment
3003.10 Unauthorized Use
3003.11 Exposure to Fire
3003.12 Leaks, Damage, or Corrosion
3003.13 Surface of Unprotected Storage or Use Areas
3003.14 Overhead Cover
3003.15 Lighting
3003.16.13 Accessway
3004 Storage of Compressed Gases
3005 Use and Handling of Compressed Gases
3005.1 Compressed Gas Systems
3005.2 Controls

3005.3 Piping Systems
3005.4 Valves
3005.5 Venting
3005.6 Upright Use
3005.7 Transfer
3005.9 Material-Specific Regulations
3005.10 Handling
3203.4 Liquid Marking
3503.1 Quantities Not Exceeding the Maximum Allowable Quantity per Control Area
3503.1.2 Storage Containers
3503.1.3 Emergency Shutoff
3503.1.4 Ignition Source Control
3503.1.5 Electrical
3503.2 Quantities Exceeding the Maximum Allowable Quantity per Control Area
3504.2 Outdoor Storage
3504.2.1 Distance Limitation to Exposures
3505 General Use

International Fuel Gas Code (International Code Council, 2009)

301 General
302 Structural Safety
303 Appliance Location
305 Installation
409 Shutoff Valves
633 Stationary Fuel Cell Power Systems
635 Gaseous Hydrogen Systems
703.2 Containers, Cylinders, and Tanks
703.3 Pressure Relief Devices
703.4 Venting
703.5 Security
703.6 Electrical Wiring and Equipment
704 Piping, Use and Handling
705 Testing of Hydrogen Piping Systems
706 Location of Gaseous Hydrogen Systems

International Mechanical Code (International Code Council, 2009)

301 General
302 Protection of Structure
303 Equipment & Appliance Location
304 Installation
305 Piping Support
401 General
501 Exhaust Systems
502 Required Systems
510 Hazardous Exhaust Systems
924 Stationary Fuel Cell Power Systems

926 Gaseous Hydrogen Systems

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

7.1.1 Listed and Approved Hydrogen Equipment
7.1.2 Containers, Cylinders and Tanks
7.1.3 Listed and Approved Hydrogen Equipment
7.1.4.3 Physical Protection
7.1.6 Separation from Hazardous Conditions
7.3.1.4 Valves
7.6 Flammable Gases
10.2 Design of Gaseous Hydrogen Systems
10.2.1 Pressure Relief Devices
10.2.1.1 Venting Requirements
10.2.5 Marking
10.3 Location of Gaseous Hydrogen Systems
10.3.2 Specific Requirements
10.4.1.2 Electrical Equipment Location
10.6 Fire Protection

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)

4.2 Prepackaged, Self-Contained Fuel Cell Power Systems
4.3 Pre-Engineered Fuel Cell Power Systems
4.4 Engineered and Field-Constructed Fuel Cell Power Systems
5.1.1 General Siting
5.1.1 (2) General Siting
5.1.2 General Siting
5.1.3 General Siting
5.2 Outdoor Installations
6.1.2 General
6.4.1 Gaseous Hydrogen Storage
6.4.1 Ventilation Air
6.4.3 Hydrogen Piping
6.4.3.2 Hydrogen Piping
6.4.3.5 Hydrogen Piping
6.4.3.7 Hydrogen Piping
6.4.3.1 Hydrogen Piping
7.1.1 General
7.2.2 When Natural ventilation Permitted
7.3 Exhaust Systems
8.1.2 Fuel Cell Fire Protection and Detection
8.1.3 Electrical Equipment and Components
9.2 Outdoor Installations
9.5 Fire Protection

Operation Approval

Codes and Standards Citations for Stationary Fuel Cell Applications

ANSI/CSA America FC 1-2004, Stationary Fuel Cell Power Systems (American National Standards Institute and Canadian Standards Association, 2004)

- 1.18.2 Maintenance Manual
- 1.19.1 Materials for Markings
- 1.19.2 FC Labeling Requirements
- 1.19.4 - 1.19.7 Electrical Diagrams

CGA P-1, Safe Handling of Compressed Gases in Containers (Compressed Gas Association, 2006)

- 4.1 Transportation Regulating Authorities
- 4.2 Container Regulations
- 4.3 Container Filling Regulations
- 4.4 Regulating Authorities of Employee Safety and Health
- 6.2 Flammable Gases

International Fire Code (International Code Council, 2009)

- 105.6.8 Compressed Gases
- 404.3.2 Fire Safety Plans
- 406 Employee Training and Response Procedures
- 2703.2.6 Maintenance
- 2703.5 Hazard Identification Signs
- 2703.6 Signs
- 2705 Use, Dispensing, and Handling
- 3003.4 Gas Marking
- 3003.9 Service and Repair
- 3003.16.13 Accessway
- 3005.7 Transfer
- 3203.4 Liquid Marking
- 3505 General Use

International Fuel Gas Code (International Code Council, 2009)

- 707 Operation and Maintenance of Gaseous Hydrogen Systems

NFPA 55, Compressed Gases and Cryogenic Fluids Code (National Fire Protection Association, 2010)

- 4.6 Personnel Training
- 4.7 Fire Department Liaison
- 7.1.3 Listed and Approved Hydrogen Equipment
- 7.3.1.10 Use and Handling
- 8.3.5 Overfilling
- 10.2.5 Marking
- 10.3 Location of Gaseous Hydrogen Systems
- 10.6 Fire Protection

NFPA 853, Standard for the Installation of Stationary Fuel Cell Power Systems (National Fire Protection Association, 2007)

- 6.1.2 General
- 6.4.1 Gaseous Hydrogen Storage
- 6.4.3 Hydrogen Piping
- 8.2 Fire Prevention and Emergency Planning

Recommendations on any compliance issues

One important compliance issue that this project had was siting the hydrogen storage system for the fuel cell. One way to improve the siting process is to evaluate multiple locations for the fuel cell to determine whether there is a location that does not present siting issues. The siting issues referred to are the separation distances from exposures that bulk hydrogen systems must meet or comply with NFPA 2 Hydrogen Technologies Code 2011 edition. Hydrogen storage systems for stationary fuel cells typically fall into the greater than 250 psi and less than or equal to 3000 psi pressure range.

For the following exposures the there must be a 45 foot separation distance between the hydrogen storage system and the exposure:

1. Lot lines
2. Openings in buildings of fire rated or non-fire rated construction that have openable doors windows, or other openings
3. Ignition sources
4. Air intakes

These separation distances can pose difficulties for siting systems in even relatively unconstructed spaces.

Recommendations on how the findings could be applied to other projects

For all projects a pre design meeting with the enforcing authority should be held to describe the project and agree on which requirements the projects would be subject to. Because hydrogen storage system siting is likely a key compliance issue, this meeting would be an opportunity to review possible hydrogen storage system locations.

IV Conclusions

This report evaluated two emerging fuel cell projects for safety and codes and standards compliance. The backup power installation project was reviewed prior to construction so information on fuel cell operation could not be included in the report. The forklift project was evaluated after extensive construction and operational history.

There are a few overarching conclusions that apply to both projects:

1. There are codes and standards in place that specifically address the emerging fuel cell technologies that are the subject of this report
2. Although compliance with codes and standards does involve a significant effort, it does not prevent project implementation
3. Projects of similar complexity are subject to similar levels of control and the codes and standards compliance effort is of similar magnitude (Conversations with Fiedler Engineering)
4. A thorough codes and standards review early in the design or project development process has the potential to reduce codes and standards compliance issues resulting in shorter project review times and cost savings
5. Evaluating operator work structure and needs can increase the effectiveness of the technology and this evaluation should be performed as early in the project development process as possible.
6. Although a proposed project submission may show compliance with codes and standards the Authority Having Jurisdiction (AHJ) still has a lot of latitude in evaluating the project and requiring that additional safety measures be employed.

Another key to moving a project efficiently through the permitting process that was not addressed in the MCLB project is meeting with the AHJ prior to submitting a permit application or in the case of DoD facilities the documentation required to show compliance with UFC 3-600-01. This meeting that precedes submitting an application has the following objectives:

Acquaint the AHJ with the project technology

Perform a detailed review of codes, standards, and regulations to ensure that both the permit applicant and the AHJ agree on what requirements the project must meet

Discuss the time frame for processing the application to ensure there is a common understanding of the process and time required to issue a permit or approval

Discuss the documentation required with the submission to ensure that the permit when submitted is complete

Review permits issued for similar installations to understand what compliance conditions might be placed on the operation

Discuss any recordkeeping or data reporting requirements that might be required to ensure that ongoing operations stay compliant.

Citations

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