SAFETY OF HYDROGEN POWERED INDUSTRIAL TRUCKS, LESSONS LEARNED AND EXISTING CODES AND STANDARDS GAPS

Harris, A.[1] and Rao, P.[2]
[1] Nuvera Fuel Cells, 129 Concord Rd, Billerica, MA, 01821, United States, aharris@nuvera.com
[2] Nuvera Fuel Cells, 129 Concord Rd, Billerica, MA, 01821, United States, prao@nuvera.com

ABSTRACT

This paper provides an introduction to the powered industrial truck application of fuel cell power systems, the safety similarities with the automotive application and safety lessons learned. Fuel Cell niche markets have proven their value to many early adopters. How has the automotive market provided a springboard for these niche applications? How are niche markets revealing gaps in current safety approaches? What is different about the powered industrial truck application and what new codes and standards are needed to accommodate those differences?

1.0 INTRODUCTION

Over the past 5 years industrial trucks surged to the forefront of fuel cell vehicle applications. With more than 1000 vehicles and over 300,000 refueling events, the industrial truck market has entered the ‘early market’ phase of technology introduction. Much of this success is credit to development of light duty passenger vehicle fuel cells and refueling stations. Hydrogen powered industrial trucks are an ideal application for further advancing hydrogen safety, codes and standards. The industrial truck might also serve as a proving ground for components, methods and processes which apply to the broader vehicle market.

2.0 INDUSTRIAL TRUCKS

2.1 Introduction to the Industrial Truck Market

Industrial trucks, often called ‘forklifts’ are used in many industries. There are several types of industrial trucks, typically categorized by the type of fuel used: propane, compressed natural gas, gasoline and diesel. There are also electric trucks powered with a flooded, lead-acid battery. Most grocery and consumer goods warehouses use electric powered industrial trucks due to many factors including zero emissions. Hydrogen fuel cells systems are designed to replace the flooded, lead-acid battery in electric industrial trucks.

Hydrogen fuel cell systems for industrial trucks share some aspects of other fuel cell vehicle applications. Both vehicles use fuel cell systems to power electric drive motors. Both vehicles take advantage of electric vehicle energy recovery through regenerative braking. Fuel cell systems in industrial trucks are hybrid systems where fuel cells are combined with batteries or ultra-capacitors for electrical capacity and peak loads.

Hydrogen fuel cell systems for industrial trucks differ from other fuel cell vehicle applications in weight, range and load profile. The electric industrial truck uses the battery as counterweight for lifting loads. Therefore, unlike the light duty vehicle application, fuel cell systems for industrial trucks must be as heavy as possible to meet the equivalent weight of a similar sized lead-acid battery. The hydrogen powered industrial truck operates in the limited space of a warehouse. Therefore the range of the hydrogen powered industrial truck is defined by the time between refueling events rather than the distance driven. In most warehouses the industrial trucks operate at maximum power for long periods of their operational life. Conversely many other fuel cell vehicle applications operate at idle or low power consumption for long periods of their operational life. Despite these differences, fuel cell systems originally developed for other vehicle applications have demonstrated strong performance with industrial trucks.

Warehouse operators are attracted to fuel cell systems due to productivity improvements and increased floor space. A typical worker will spend 15-20 minutes per 8 hour shift changing batteries; this is a loss of worker productivity. The fuel cell system is refuelled, not swapped. The typical worker will spend 5-10 minutes per 8 hour shift refueling a hydrogen system. Workers also take advantage of lunch or coffee breaks to "opportunity refuel" thereby further increasing productivity. The battery charging infrastructure must be located indoors, either in a dedicated battery room or on the warehouse floor, in either case this is 'wasted' space. Hydrogen infrastructure is located outside, freeing floor space for product storage.

The hydrogen powered industrial truck (HPIT) market has grown quickly. Since early prototypes rolled out in 2005, there are now more than 1000 vehicles. This rapid growth has pushed the development of hydrogen infrastructure. Hydrogen stations supporting industrial trucks have performed over 300,000 refueling events and the rate of refueling events increases each week.

Hydrogen infrastructure – hydrogen production, storage and dispensing – is often cited as the limiting factor for the light duty vehicle application. This was well understood early in the development of light duty vehicles; consider the 2002 National Hydrogen Energy Roadmap stated that successful market transformation needed to "coordinate 4 industrial segments (Production, Delivery, Storage and Application) as one system" [1]. The roadmap identified three keys to successful advancement of infrastructure: 'captured fleets', field experience and a simplified infrastructure. The industrial truck market depicted in Figure 1 meets all of the criteria.

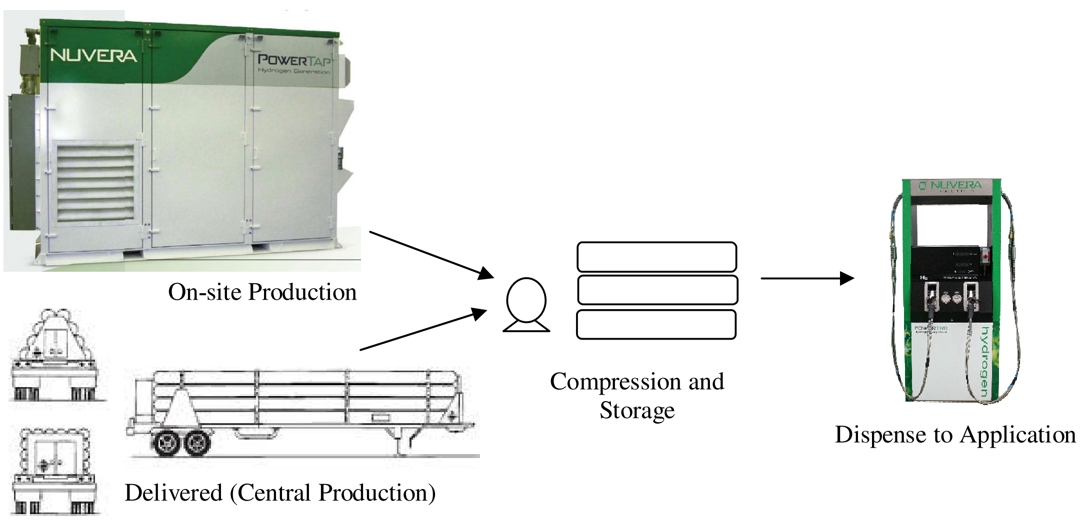

Figure 1 The industrial truck fuel cell application system - Production, Delivery, Storage, Application

The hydrogen infrastructure at a warehouse is less complicated than light duty applications. The warehouse system uses lower pressures and does not require metering. Hydrogen powered industrial trucks operate at lower pressures; 25MPa and 35MPa, whereas most light duty vehicles need 70MPa for optimum range. The lower operating pressure eliminates many complexities of the fueling infrastructure such as: gas pre-cooling, complex fill algorithms, communication between vehicle and dispenser, and high pressure component costs. Hydrogen is not sold at the pump in the warehouse; this eliminates expensive metering and further simplifies the dispenser.

The high capital cost versus the low return on investment for a hydrogen fueling station is a major roadblock to light duty vehicle deployments. Fueling stations require high utilization to become profitable. Two factors affect utilization: the number of vehicles serviced by a single station and the frequency of refueling events per vehicle. The ideal refueling situation is called a 'captured fleet' where all vehicles must use a single refueling station. Examples of 'captured fleets' include airport shuttle buses, postal delivery vans and industrial trucks. Consider that a single warehouse may hold hundreds of industrial trucks. Of the 'captured fleets' industrial trucks are the most heavily used, often requiring 3-5 refueling events per vehicle per day. High volume warehouses operate 24 hours per day, 7 days per week further increasing the utilization of the hydrogen infrastructure.

Hydrogen powered industrial trucks and hydrogen fueling stations replace existing overhead costs for the warehouse manager. Unlike the light duty vehicle market, the warehouse manager owns both the vehicles and the infrastructure. The fuel cell systems replace the batteries and the fueling station replaces the battery charging equipment. This simplifies the deployment process and eliminates the free-market negotiation between vehicle owners and fuel suppliers found in the light duty vehicle market.

The introduction of hydrogen powered industrial truck and hydrogen refueling systems into the warehouse environment presents several challenges to the development of safety, codes and standards Some of these challenges were already faced with other vehicle applications, other challenges are unique to industrial trucks.

2.2 What are the codes and standards?

The hydrogen industrial truck application must be 'as safe or safer' than the battery technology that it replaces. Figure 2 describes the current codes and standards associated with hydrogen powered industrial trucks.

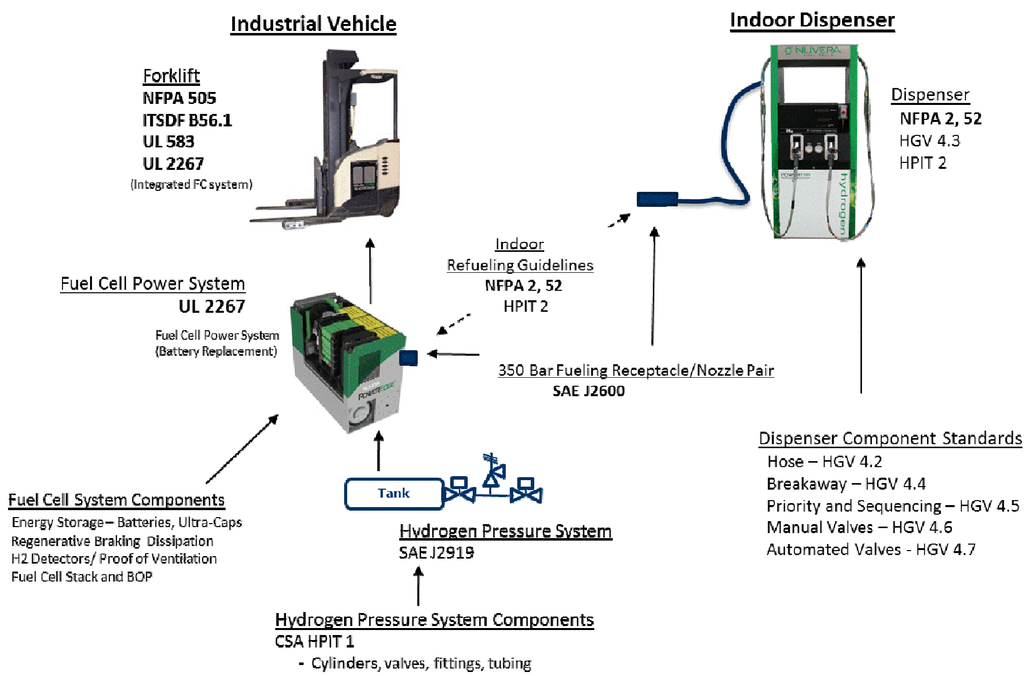

Figure 2 Hydrogen Powered Industrial Truck Codes and Standards Reference Paths (Published Standards in bold)

Safety codes and standards cover 3 aspects of the hydrogen powered industrial truck application: fuel cell system design and performance, fueling system design and performance and hydrogen refueling protocol.

UL 2267 [2] covers the design and performance of fuel cell systems for hydrogen powered industrial trucks. Developed in 2006 and updated in 2011, this standard provides component and system test requirements for both battery replacement fuel cell systems or fully integrated fuel cell industrial trucks. A similar standard IEC 62282-4 has recently started development.

There are several related standards which also provide guidance for industrial truck applications. NFPA 505 [3] provides guidance and sets limitations on the use of industrial trucks in hazardous environments. NFPA 505 currently limits hydrogen powered industrial trucks to non-hazardous environments, or Type E trucks. The most recent revision of NFPA 505 created a new category for hydrogen fuel cells, Type CGH. This designation will cover fully integrated fuel cell powered industrial trucks. NFPA 505 does not yet cover conversion of Type E trucks into Type CGH trucks.

UL 583 [4] and ITSDF B56.1 [5] cover industrial truck design and use. UL583 outlines the test methods and performance requirements for certification of newly built industrial trucks and ITSDF B56.1 details safety requirements for low-lift and high-lift trucks. Hydrogen fuel cells are not yet referenced specifically in UL583 or ITSDF B56.1.

Industrial trucks have leveraged past work from light duty applications for refueling and process plumbing. Table 1 summarizes the developing standards and the automotive reference.

Table 1 Industrial Truck Codes and Standards with light duty vehicle references

Industrial Truck Standard (under development)	Automotive Reference (published)
CSA HPIT 1 – Fuel system components	CSA HGV2, CSA HGV 3.1
SAE J2919 – Fuel storage subsystem	SAE J2579
SAE J2601-3 – Indoor fueling protocol	SAE J2601-1
CSA HPIT2 – Indoor dispenser components	CSA HGV 4.3

Refueling operations for hydrogen powered industrial trucks are governed by NFPA 52 [6] and NFPA 2 [7]. These codes specify the dispenser installation requirements and the maximum fill pressure. These codes also identify the dispenser as bearing the responsibility for safely filling listed or approved vehicles. A single refueling protocol is not yet prescribed in the codes although several equally safe methods are in use today. NFPA 52 and NFPA 2 are good examples of the benefits of automotive investment. Years of development and government supported research helped establish these codes for use by automotive demonstrations. Industrial truck applications have entered the market more easily because of this prior work.

In some places the codes and standards are harmonized. For example, NFPA 52, NFPA 2 and UL2267 all reference the same refueling requirements and component standards. One of these standards, SAE J2600 [8], covers the design of the refueling nozzle and the on-board receptacle. This interface between vehicle and dispenser sets standard operating pressures and therefore identifies the pressure rating of components for both the dispenser and the vehicle. SAE J2600 also prescribes the design of the nozzle and receptacle to mechanically prevent filling a lower pressure system with a higher pressure nozzle. A great deal of effort went into developing the SAE J2600 standard for light duty vehicle demonstrations. Industrial trucks would not be a market today without SAE J2600. Another harmonized standard, ASME B31.12 [9], prescribes the piping and plumbing design requirements for both the dispenser and the vehicle. Although the use of this single standard for both the dispenser and vehicle clarifies much of the design, a difference in the interpretation of terminology still exists.

Industrial trucks need to further expand the codes and standards specific to the application. Several standards are in the process of development. All of these standards are based on existing light duty vehicle standards. In addition to the new documents, revisions to UL 2267, NFPA 52, NFPA 2, UL 583 and NFPA 505 are in progress.

What are the safety challenges faced by the indoor application of hydrogen powered vehicles? How do these standards address them? What are the remaining gaps in these new codes and standards?

2.3 Safety Challenges

Safety is paramount to any industry but the hydrogen industry seems particularly sensitive to the public perception of safety. Most people in the industry attribute this sensitivity to the public awareness of the Hindenburg airship tragedy. In order to facilitate widespread acceptance, early adopters of fuel cell technology must have confidence in the safety of the fuel cell systems and refueling infrastructure. That confidence is achieved by robust technical assessment and industry collaboration on safety, codes and standards.

The safety challenges for powered industrial trucks may be categorized by exposures: struck by/crush hazards, flammable gas release, hot surfaces, and the release of hazardous energy (overpressure, electrical shock). Hydrogen fuel cell operation can positively or negatively affect all of these exposures [10].

Industrial truck operation of any kind remains a dangerous occupation. The US Bureau of Labor and Statistics reported 57 deaths related to industrial trucks in 2009. Fuel cell applications must be as safe as or safer than the current technology. Many incidents today are related to "struck by" or "crush" hazards associated with industrial trucks. These accidents have a number of contributing factors which could include tip-over, delayed response or operator distraction.

Tip-over is a safety concern for many types of industrial trucks. Power systems in many industrial trucks serve as the counterweight. In particular high lift trucks are susceptible to tip over. The fuel cell system must replace all aspects of the battery including weight. While this is a challenge for fuel cell system integrators, early identification of this issue lead to clear communication of requirements between fuel cell system integrators and industrial truck original equipment manufacturers (OEMs). Standardization of this process remains an open item for NFPA 505, UL2267 and UL583. The NFPA 505 "conversion kit" approach is a good place to address this gap. NFPA 505 provides guidance for converting a propane truck to compressed natural gas. This same approach may be appropriate for replacing a battery with a fuel cell system.

The fuel cell system can affect the vehicle response. Improperly designed fuel cell systems could fail to absorb regenerative braking energy leading to delayed braking response. Newer electric industrial trucks use regenerative braking similar to light duty hybrid and electric vehicles. In some vehicle types a mechanical brake is also used in addition to regenerative braking however, this mechanical brake is commonly activated by the operators foot pedal rather than the directional controls. Fuel cell systems will not affect the function of the mechanical brake however fuel cell systems must be capable of absorbing the regenerative energy in order to ensure proper operation of regenerative brakes. Failure to absorb regenerative energy could affect the operator's response time to avoid accidents. Regenerative braking absorption is a gap in the current standards. Industrial truck OEMs currently provide informal validation testing and certification of fuel cell systems to compensate for this and other codes and standards gaps [11].

Other hazards in operation may result from the distraction of new technology. Fuel cell systems today replace batteries in existing industrial truck models. Additional user interfaces are required to control the fuel cell system or provide low fuel level warning. Operators could be more distracted leading to an increased likelihood of accidents. OSHA section 1910.178, NFPA 505 and ITSDF 56.1 all require training for operators. Training provided in current deployments appears sufficient; much of this is assisted by an industrial truck industry effort to reduce accidents in recent years through more comprehensive training [12]. The broader fuel cell industry can ill afford negative perception from early adopters.

Many varieties of user interfaces are in use today. A user interface design standard could reduce the chance of operator confusion. Unlike the passenger vehicle which integrates the fuel cell into the vehicle design, the industrial truck is designed for a battery, therefore the fuel cell user interface must be "added on" to the truck. Some type of user interface is necessary for the fuel cell system as the operator must be aware of the fuel level. Several varieties of fuel cell system user interface also provides warning when service is required, start/stop controls and data transmission. Several questions remain regarding the requirements for user controls such as: Does the operator also need manual override of the fuel cell control system? Should the vehicle emergency stop control the fuel cell operation?

Operation of hydrogen powered industrial trucks changes the likely location of flammable gas release. In battery powered systems hydrogen is routinely released during recharging, therefore the flammable gas release is limited to one area in the facility. Hydrogen in the fuel cell hybrid system is not routinely released, however the vehicles carry the hydrogen with them, therefore a potential for flammable gas release exists wherever those vehicles travel. Flammable gas releases are best mitigated with leak prevention, leak detection and dilution. The fuel cell system standard, UL2267 references ASME B31.12 for process plumbing design which includes leak prevention and leak testing. The conservative approach in ASME provides sufficient safety margin in the material strength of high pressure containment; leak prevention. The leak testing process prescribed in ASME ensures that each system meets strict requirements. UL2267 specifies that fuel cell systems provide hydrogen leak detection and/or dilution means through ventilation. UL2267 also requires an automatically operated shut off valve. Although not specified, this valve may be activated by a variety of safety sensors including crash detection, hydrogen detection or loss of ventilation.

Another source of flammable gas release is indoor hydrogen refueling. For many industrial truck applications refueling is conducted indoors. Use of hydrogen indoors is not new, however the high pressures and frequent make/break connections associated with refueling make this application unique. NFPA 2 and NFPA 52 provide guidance for the installation and operation of indoor hydrogen refueling stations. CSA HPIT-2 is a standard in development. HPIT2 will provide guidance for the design and performance of industrial truck dispensers, including indoor applications. SAE J2601-3 is also under development. J2601-3 will provide a protocol for refueling, particularly with regard to gas temperature limits for plastic reinforced, composite tanks. Industrial trucks are an ideal environment to test or develop alternative methods for safe refueling such as vehicle self-identification.

The electric industrial truck may not typically be associated with hot surfaces (loosely defined as surface temperatures above 120 F). However due to heavy use, the vehicles, the batteries and particularly the load cables can exceed these "touch safe" surface temperatures. Fuel cell powered systems introduce heat management systems to the industrial truck application. Hot exhaust from a fuel cell can reach temperatures at or above 160 F. We routinely accept these temperatures and exposures in relationship to internal combustion engine exhaust however existing electric vehicle applications are not accustom to this type of exposure. UL2267 provides guidance to prevent an "unsafe situation", which could include hot exhaust; although "unsafe situations" are left to the individual OEM's hazard analysis. UL583 addresses the maximum temperatures the components of the vehicle must withstand during heavy operation but does not address "touch safe" temperatures. OSHA requirements provide the necessary guidance to end users for protecting employees. Harmonization of the UL 583 and UL2267 documents along with OSHA guidance regarding maximum allowable surface temperatures may provide fuel cell OEMs with better guidance in this area.

The hydrogen powered industrial truck also changes the exposure to hazardous energy. There are two sources of hazardous energy in the application: high pressure gas and electrical circuits greater than 50V.

The hydrogen storage system has two operating pressures, 250 bar (3626 psi) or 350 bar (5076 psi), both of these pressures are generally considered high pressure although a global definition of "high pressure" does not exist in codes and standards. The operators are at the greatest likelihood of exposure during refueling. Similar to gasoline refueling of light duty vehicles, the exposure occurs as the operator must make and break a connection between the vehicle and the station. The SAE J2600 nozzle/receptacle standard has proven safe refueling in hundreds of thousands of refueling. The "block and bleed" function of nozzle ensures that gas trapped in the disconnecting process is safely vented. UL2267 specifies the use of SAE J2600 receptacles. UL2267 also specifies the storage system component requirements. These storage requirements were revised in January 2011 to address concerns regarding cyclic fatigue of type 1 (steel) storage vessels. An on-going experiment sponsored by the US Department of Energy through Sandia National Laboratories will help determine the expected life of these cylinders. Design guidance and validation requirements based on Sandia's research are expected to appear in the hydrogen powered industrial truck component standard - CSA-HPIT1.

Fuel cell vehicles are electric vehicles. For industrial trucks the electrical power buss is 36 or 48 VDC. Therefore the vehicle systems are below the 50V threshold established by OSHA for hazardous electrical equipment. The output power from the fuel cell hybrid system matches the battery output (36 or 48 VDC), however internal voltages of the fuel cell stack upstream of power conditioning may exceed OSHA's 50V threshold. UL2267 outlines testing requirements for electrical components and performance testing for the overall system. training of maintenance personnel for fuel cell systems will need to include hazardous energy isolation methods to comply with OSHA. Another electrical safty gap exists between UL2267 and UL583 regarding interactions between fuel cell system and vehicle, the standards address current flowing from the fuel cell system to the truck but do not address current flowing from truck to fuel cell.

OSHA's "Green Job Hazards" website, related to hydrogen fuel cells also identifies freeze burns related to cryogenic hydrogen. The fuel cell powered industrial trucks are powered by gaseous hydrogen at ambient temperatures. Cryogenic hydrogen exposure is only applicable for some types of bulk fuel storage and is therefore not an exposure for vehicle operators. NFPA 55 [13] provides guidance for siting both cryogenic and compressed hydrogen storage systems.

3.0 COMPARISON OF INDUSTRIAL TRUCKS AND LIGHT DUTY VEHICLES

3.1 How do industrial trucks relate to the automotive market?

Hydrogen powered industrial trucks are a market unto themselves, however there is a strong link between industrial trucks and light duty vehicles. As this smaller, industrial truck market expands, experience with industrial trucks and other "captured fleets" will provide valuable experience for the commercial phase of light duty vehicle fuel cell systems.

On-board storage is a key difference between industrial trucks and light duty vehicles. The industrial trucks need much less storage volume since there is constant access to refueling. It is often more cost effective to increase worker productivity by adding dispensers, rather than adding on-board storage. Light duty vehicle applications are not as lucky and must compete with the range of gasoline engine systems, typically 300 miles. Several studies are underway to better understand the influence of refueling access upon range requirements for light duty fuel cell vehicles [14]. Other differences in the storage systems such as counterweight were discussed earlier.

Most light duty passenger cars are not used as heavily as most industrial trucks. Light–duty passenger cars, even heavy use applications such as taxis, spend a majority of time at low power, idling at stoplights or in traffic. Industrial trucks, particularly class 2 lift trucks spend the majority of time at high power. Furthermore, many industrial trucks are operated 24/7 with one operator replacing another every 8 hours. Consider the economic incentives which drive the operators of these vehicles, the taxi cab is capable of making money regardless of power consumption whereas the lift truck operators are often incentivized by the number of order exchanges or "picks" performed in a single shift. Therefore the lift truck operator maximizes the power of the vehicle. These extreme use environments are providing valuable data on fuel cell stack durability, component reliability and fueling station design.

The frequency of use and the smaller fuel storage on the industrial truck means significantly more refueling events. The use of steel tanks and the frequency of refueling for industrial trucks uncovered safety concerns regarding the durability of steel tanks, specifically hydrogen assisted cyclic fatigue. The US Department of Energy responded to these concerns by initiating a test program through Sandia National Laboratories to better understand this phenomenon. As stated previously these test results will directly influence the CSA – HPIT1 standard. The test results will influence material compatibility requirements in other hydrogen standards such as CSA-CHMC.

A comparison of industrial trucks and light duty passenger vehicles is shown in Table 2.

Table 2 Comparison of industrial trucks and light duty vehicles

Function	Industrial Truck	Light Duty Vehicle
Storage	8hr Shift	300 miles
Power	Peak power	Optimized (idle and peak)
Weight	Heavy is good	Light is good
Hybrid	Replaces battery	Replaces engine
Operational Life	<10yrs	20yrs
Environment	Indoors (freezers)	Outdoors
User Interface	Separate	Integrated
System Pressure	250 or 350 bar	700 bar

Industrial trucks and light duty vehicles share common interest in the advancement of fuel cell and component technologies. The experience gained in industrial trucks will accelerate technology improvements in fuel cell stack manufacturability and durability. Market expansion also improves volumes for component manufacturers, which in turn makes certified components more available.

The greatest benefit which industrial trucks provide to light duty vehicles is the development of hydrogen fueling infrastructure. Fueling infrastructure providers gain valuable experience with fueling control algorithms, effective safety devices and operator training. Infrastructure deployments force fire officials and insurers to review site plans against the model codes. This increases experience and confidence in the safe operation of hydrogen refueling stations.

3.2 Codes and Standards Gaps

Assessment of the safety experiences and the existing gaps in codes and standards requires a level of humility as it exposes areas for improvement. Gaps in the codes and standards are detailed previously in this document. A short list is provided here for reference:

- UL2267, UL583, ITSDF 56.1 and NFPA 505 coordination on for acceptable "conversion kits" for Type E industrial trucks – also determining how to retroactively address the existing 1000+ fuel cells currently in use.
- UL 2267, UL583 and ITSDF 56.1 considerations for limiting operator distractions while optimizing user interface
- NFPA 505 – development of a "conversion kit" portion of the standard similar to the existing description of converting a propane vehicle to compressed natural gas. This would facilitate the current practice of replacing batteries with fuel cell systems.
- NFPA 52, NFPA 2, HPIT 2, UL2267, SAE J2919 coordination on refueling standards
- UL2267 and SAE J2919 guidance for fuel cell system OEMs regarding appropriate test methods for leak and pressure testing
- UL2267 and UL583 coordination on regenerative braking requirements
- UL2267 guidance on appropriate installation of storage vessels in vehicles, particularly based on recent failures of NGV tanks.
- UL2267 and NFPA 505 addressing decommissioning vehicle systems, particularly storage vessels, again based on experiences in aftermarket or repurpose of NGV tanks
- UL2267, SAE J2600, SAE J2579 coordination to evaluate the likelihood an implications of refueling a forklift at a light duty vehicle dispenser or vice versa.

3.3 Lessons Learned

Field experience continues to provide Nuvera Fuel Cells with valuable lessons learned in regard to the design, manufacturing, installation and commissioning processes.

Several design related topics were discussed previously: ensuring counterweight, tank type selection, regenerative braking and user interface. In one experience Nuvera learned to appropriately size the system enclosure for all refueling connections. The SAE J2600 nozzle has two types, communication and non-communication. The communication nozzle has a larger diameter to accommodate communication equipment. Nuvera's original enclosure design used the dimensions of the smaller, non-communication nozzle, thereby preventing the larger communication nozzle from connecting to the receptacle. Retrofit of units to accommodate the larger nozzle was an inconvenient modification.

The manufacturing process brings its own set of safety issues. In addition to the concerns for worker safety listed previously there are other concerns related to the manufacturing line. A lack of harmony in the current standards makes it unclear how to appropriately pressure test the high pressure subsystem. At the center of the issue are references to NFPA 52 and NFPA 2 which specify the overpressure allowance during dispensing: 125% of service pressure. On the vehicle side, UL2267 references both 125% and the ASME B31.12 Hydrogen Piping and Plumbing standard. The ASME standard requires a pneumatic pressure test to 110% of design pressure or a hydrostatic test to 150% of the design pressure. It is not entirely clear how to correlate the definition of design pressure and the definition of service pressure.

During commissioning of the vehicles there is an opportunity to establish a safety culture among the operators. A recent experience by Nuvera customer care department illustrates the intersection of new technology with unfamiliar end users. In the weeks and months after the initial training, Nuvera's customer care team communicates with operators and observes refueling activities. Often these interactions prove beneficial to improving the design of the fuel cell system or the dispenser as well as improving operator understanding. A customer care team member related an example of this interaction recently from an installation in San Antonio, TX. The Nuvera customer care member casually asked an operator at about the use of the dispenser. The operator replied, "I connect the nozzle and watch for the dial to read 5000 gallons". The customer care member took a second to consider the statement. It was clear that English was not the operator's native language. The customer care member used Spanish to confirm that the operator intended to say pounds per square inch (psi). Later the customer care member reflected that it may not be important for operators to appreciate the difference between gallons and psi. In fact there are likely many drivers on the road today who don't really know what a gallon of gasoline is. It was important that the value, 5000, was retained by the operator from the initial training. It was also important that the operator assimilated refueling the forklift to refueling his personal car.

The end of useful life is an issue for all compressed gas vehicles. The current CNG fleet has suffered setbacks due to resale and reuse of containers after the end their design life. All hydrogen vehicle OEMs need to consider the implications of aftermarket use of components. It is difficult to control the actions of private individuals but OEMs can work through codes and standards to develop reasonable guidelines to prevent misuse or abuse.

4.0 SUMMARY

The similarities between industrial trucks and other vehicle applications are opportunities to leverage experience from one market segment to another. Automotive demonstration projects pushed the development of safety, codes and standards. This eliminated barriers for the industrial truck market. Growth of viable, smaller markets like industrial trucks will further develop safety, codes and standards, particularly for hydrogen infrastructure. Demonstration of the 4 key market segments, production, delivery, storage and application in an unsubsidized market like industrial trucks will prove the viability of fuel cells for larger markets.

Experience in vehicle applications improves the technology. Aggressive applications like industrial trucks accelerate fuel cell stack innovation, in turn extending ranges for light duty vehicles.. Improvements in common components such as batteries, pumps and motors will positively affect all applications. Engineering experience with hybrid system control algorithms and fuel cell system reliability data can also drive innovation. The refueling experience, the human interface and safety systems must meet the user's expectations in all vehicle applications. A broad industry approach to lessons learned and standards gaps enables accelerated advancement in building better, safer fuel cell systems.

Hydrogen infrastructure developed for industrial trucks may provide the greatest benefit. Industrial warehouse sites may bridge the gap in existing refueling stations. While it may not yet be profitable to place hydrogen at the corner gas station, a warehouse using hydrogen for hundreds of forklifts could support a small demonstration fleet of cars. The frequency of use and demanding environment will also challenge refueling infrastructure design yielding many lessons learned for retail applications.

In the current economic and political environment there is more to be gained from collaboration than lost to competitive advantage.

5.0 REFERENCES

1. Davis, M., Balog, F., Nemanich, G., Karsaros, A., Ogden, J., Niedzwiecki, A., and Serfass, J. National Hydrogen Energy Roadmap. Unites States Department of Energy National Hydrogen Energy Workshop, November 2002. www.hydrogen.energy.gov/pdfs/national_h2_roadmap.pdf

2. Underwriters Laboratories. UL 2267 Fuel Cell Power Systems for Installation in Industrial Electric Trucks. 2011. Underwriters Laboratories, Northbrook, IL

3. Technical Committee on Industrial Trucks. NFPA 505 Fire Safety Standard for Powered Industrial Trucks Including Type Designations, Areas of Use, Conversions, Maintenance, and Operations. 2011 Edition. NFPA, Quincy, MA

4. Underwriters Laboratories. UL 583 Electric-Battery-Powered Industrial Trucks. 2007. Underwriters Laboratories, Northbrook, IL

5. ITSDF Standards Committee. ANSI/ITSDF B56.1-2009 Safety Standard for Low Lift and High Lift Trucks. 2009. Industrial Truck Standards Development Foundation, Washington DC.

6. Technical Committee on Vehicular Alternative Fuel Systems. NFPA 52 Vehicular Gaseous Fuel Systems Code. 2010 Edition. NFPA , Quincy, MA

7. Technical Committee on Hydrogen Technology. NFPA 2 Hydrogen Technologies Code. 2011 Edition. NFPA, Quincy, MA

8. SAE Fuel Cell Committee. SAE International Surface Vehicle Standard SAE J2600 Compressed Hydrogen Surface Vehicle Refueling Connection Devices. 2002. Society of Automotive Engineers, Warrendale, PA

9. ASME B31 Committee Code for Pressure Piping. ASME B31.12-2008 Hydrogen Piping and Pipelines. 2009. American Society of Mechanical Engineers, New York, NY.

10. "Green Job Hazards: Hydrogen Fuel Cells" United States Department of Labor Occupational Safety and Health Administration. 2011. www.osha.gov/dep/greenjobs/hydrogen.html

11. Devlin, F., Gregory, B. Commercialization of Fuel Cells for Forklifts Proceedings of the 1st Fuel Cell and Hydrogen Energy Association Conference, 14-16 February 2011, Washington DC.

12. Preambles to Final Rules Section 4 – IV. Studies of Accident and Injury Data and Training Effectiveness. United States Department of Labor Occupational Safety and Health Administration. 2011. www.osha.gov/pls/oshaweb/owadisp.show_document?p_id=1078&p_table=PREAMBLES

13. Technical Committee on Industrial and Medical Gases. NFPA 55 Compresses Gases and Cryogenic Fluids Code.2010 Edition. NFPA, Quincy, MA

14. Stephens –Romero, S., Brown, T. and Samulsen, S. Using STREET to optimize hydrogen infrastructure investments in targeted communities. Proceedings of the 1st Fuel Cell and Hydrogen Energy Association Conference, 14-16 February 2011, Washington DC.