SAFETY CODE EQUIVALENCIES IN HYDROGEN INFRASTRUCTURE DEPLOYMENT

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ABSTRACT

Various studies and market trends show that the number of hydrogen fueling stations will increase to the thousands in the US by 2050. NFPA 2, Hydrogen Technologies Code (NFPA 2), the nationally adopted primary code governing hydrogen safety, is relatively new and hydrogen vehicle technology is a relatively new and rapidly developing technology. In order to effectively aid and accelerate the deployment of standardized retail hydrogen fueling facilities, the permitting of hydrogen fueling stations employing outdoor bulk liquid storage in the state of California.

In an effort to better understand how the applicants, consultants, and more importantly, the Authorities Having Jurisdiction (AHJ)s are interpreting and applying the NFPA 2, especially for complex applications, the newest hydrogen stations with the largest amount of bulk hydrogen storage in urban environment settings were identified and the permit applications and permit approval outcomes of the said stations were analysed.

Utilizing the pubic record request process, LH2 station permit applications were reviewed along with the approval outcomes directly from the municipalities that issued the permits. AHJs with H2 station permitting experience were interviewed. Case studies of permit hydrogen fueling station permit applications were then complied to document both the perspectives of the applicant and the AHJ and the often iterative and collaborative nature of permitting.

The current permitting time for Liquid Hydrogen (LH2) stations can range from 9 to 18 months in the California. Five out of the six LH2 stations applications required Alternative Means & Methods (AM&Ms) proposals and deviations from the prescriptive requirements of the Code were granted. Furthermore, AHJs often requested additional documents and studies specific to application parameters, in addition to NFPA 2 requirements.

1.0 OVERVIEW OF REAL LIFE LH2 FUELING STATION PERMITTING

In order to better understand how NFPA 2 is interpreted and applied in the field, the six most recent liquid hydrogen fueling stations applications were identified, which were at varying stages of completion, to assess the project complexities that lead to AM&Ms application and ascertain the factors that contribute to approval by the AHJ.

Depending on the physical location of the hydrogen fueling station application and the size, technical background and availability of the local fire prevention department, the fire permit might be ultimately issued by the city, county, or state fire marshal's office instead while the

project developers typically work directly with the local zoning department for the conditional use permit.[1]

In addition, there may be other agencies or approvals required for a hydrogen fueling station such as entitlement, zoning, public health, building, and HAZMAT, depending on the station design, space limitations, co-location of other fuel in the same lot, and impacts on nearby businesses and residences.

For urban LH2 station applications, project developers have the most challenges meeting setback distance for transfer operations, setback distance to property lines, and setback distances to source valves to bulk liquid and gaseous hydrogen storage. Applicants typically evoke the equivalency clause in Chapter 1.5 of the Code which states that nothing in the code is intended to prevent the use of systems, methods, or devices of equivalent or superior quality, strength, fire resistance, effectiveness, durability, and safety over those prescribed by this code.

AHJs have the final authority on permit decisions. Three fire AHJs with H2 station permitting experience were interviewed for their expertise. In the liquid hydrogen fueling station applications that require AM&Ms on deviations to the prescriptive requirements, AHJs often have to make a case-by-case, qualitative determination on the granting the final permit.

AHJs may also request additional alarms and emergency stops to augment applicant-proposed safety equivalences, including Active Enhanced Safety Measures and Passive Enhanced Safety Measures, as AM&Ms to the prescriptive setback distance requirements of Chapter 7 and 8 of the NFPA 2.

1.1 LH2 Fueling Station Permitting at a Glance

Six LH2 fueling stations at various stages of project development in California were surveyed. Three of the stations were commissioned in 2015, one in 2018, and three are still in the process of development. The market demand for Fuel Cell Electric Vehicles (FCEVs) has increased over the past few years and developers designed newer LH2 stations with much higher hydrogen storage capacity in order reduce operational costs.

Except for the West Sacramento station, which is situated in an industrial area, all the other LH2 Fueling Stations required AM&Ms in their permit applications as the means to meet the prescriptive setback distance requirements. Either interviews with the AHJ that made the permit decision, or a review of the permit application package were conducted on each of the stations listed below in Table 1.

	Station Name	Opening Date	Storage Capacity	AM&Ms	AHJ Interview	Application Review
1	West Sacramento	7/8/15	240KG	No	No	Yes
2	UC Irvine	11/13/15	180KG	Yes	Yes	No
3	San Juan Capistrano	12/23/15	240KG	Yes	Yes	No
4	Mountain View	2/28/18	350KG	Yes	No	Yes
5	Sunnyvale	TBD	800KG of LH2 & 100KG of GH2	Yes	Yes	Yes
6	Santa Ana OCTA	TBD	5000KG	Yes	Yes	No

Table 1. Summary of LH2 Station Permitting in CA.

1.2 Hydrogen Fueling Station Permitting Process

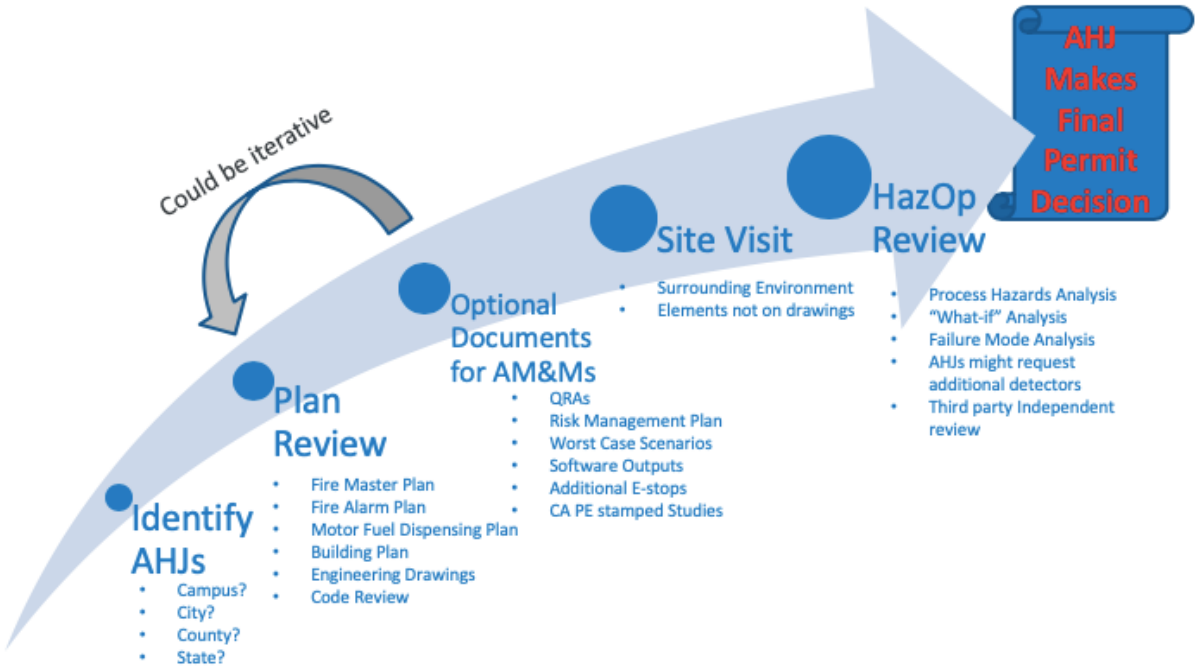

Figure 1. LH2 Fueling Station Permitting Process in CA

Depending on the location of the hydrogen fueling station, application, size, technical background and availability of the local fire prevention department, the fire department might defer to the county or state fire marshal's office to provide input on the permit approval.

After an initial meeting between the applicant and the AHJ, the AHJ typically conducts plan review on application documents that include the following: fire master plan, fire alarm plan, motor fuel dispensing plan, building plan, engineering drawing. Depending on the AHJ's familiarity with hydrogen safety and his or her knowledge of hydrogen fueling stations, the AHJ might request an independent code review of NFPA 2.

In applications where the station design doesn't meet all the prescriptive requirements of NFPA 2, station developers prepare their AM&Ms submittals with additional documentation such as Qualitative Risk Assessment (QRA), Risk Management Plan, software outputs from ALOHA or Phast, and Worst-Case Scenario Analysis. The plan review stage and the additional AM&M supporting documents stage can be iterative based on the working relationship between the developer and the AHJ. Sometimes the AHJs request that developers perform additional studies by third party professional engineers, and/or integrate additional E-Stops, detector systems and other safety measures into the station design in order to strengthen the AM&M proposal.

Depending on the developments on the surrounding property and layout of the proposed LH2 fueling station, the AHJ may choose to make a site visit to see if there are any elements not shown on drawings or google maps before conducting a hazardous operations review. During the HazOp review, the AHJ evaluates the applicant's submittals on Process Hazard Analysis, Failure Mode Analysis, and "What-if" Analysis before a final permit decision is reached. Sometimes the AHJ might ask for a third-party review of the submittals to ascertain the conclusions reached in those reports.

2.0 Case studies: Application of NFPA 2 Prescriptive Requirements and AM&Ms in the Field

2.1 West Sacramento Hydrogen Fueling Station

Figure 2.1. West Sacramento Hydrogen Fueling Station

Commissioned July 2015, the West Sacramento Hydrogen Fueling station was one of the first hydrogen fueling stations built in California with an onsite hydrogen storage capacity of 240KG, while most hydrogen fueling stations at the time had onsite storage capacities around 60 KG. Despite the higher capacity onsite liquid hydrogen storage, the West Sacramento station was permitted without the use of AMM&Ms by the City of West Sacramento, after plan check review by Fire, Planning, Engineering, and Building departments.

As a result of the industrial zoning and large lot, no AM&M was necessary because the application was able to meet the prescriptive setback distance requirements for bulk liquid and gaseous hydrogen storage systems. According to the permit application package and the fire plan check comments, the AHJ requested emergency signage on the site plan, system emergency shut down procedures, and emergency shut down controls to be implemented in addition to a separate permit application for the dispenser canopy and a redesign of the dispenser island guard posts per NFPA 2. The construction permit was ultimately granted after a third-party review by a licensed fire protection engineer.

2.2 Mountainview Hydrogen Fueling Station

Figure 2.2. Mountainview Hydrogen Fueling Station

Commissioned in Feb 2018, the Mountainview Hydrogen Fueling station was permitted by the City of Mountainview after almost a year of review by various departments such as Fire, Building, Electrical, Mechanical, Plumbing, and Land Use.

One of the challenges the developer faced, to get the fire permit approval, was meeting the 75 feet separation distance requirement from wall openings, operable openings in buildings and structures per NFPA 2 2016 Edition Section 8.3.2.3.16. More specifically, the separation distance between the liquid hydrogen delivery connection to the convenience store opening was only 54 ft.

The developer proposed the following AM&M: Vent H2 trailer through the vent stack of the stationary LH2 tank during unloading by connecting a SS transfer hose from the bulk delivery trailer to LH2 bulk storage vent stack when the trailer is to be depressurized. The following

AM&M Justifications were provided by the developer: Worst case scenario per PHAST[2] modelling result in a fully developed plume horizontal distance of 41 ft at an elevation of 8 ft,

thus giving the application a 13 ft margin with the 54 ft separation distance available. Venting of hydrogen through the stationary tank vent during the post-fill depressurization of the LH2 trailer eliminates the risk of hydrogen being present the convenience store door opening during normal operating conditions. Moreover, LH2 transfer is a manned activity by a highly trained HAZMAT driver, who could be relied upon to execute the venting procedure, which requires the operator to quickly isolate the liquid hydrogen in the transport tanker at any time by depressing either of the two automatic shutoff buttons at the back or midsection of the trailer.

The worst-case assumptions that produced a setback distance of 41 feet are as follows:

Assumptions:

4% mole fraction concentration of H2 in air Max

Full Bore leak Scenario not considered

Transfer Pipe ID: 1.5”

Transfer Pipe Length: 10’

Internal pressure of pipe: 100 psig

Leak size: 10% of ID

Leak Frequency: 1/month

Leak Release Angle: Horizontal

Leak Release Point Elevation: 1ft

Wind: 1.5m/s Tail wind

The Alternate Materials and Methods of Design and Construction proposal was processed and preliminarily approved within two months by the Mountainview Fire Prevention Bureau after the Fire Plan Check and AM&M Application Check were both completed. The applicant was able to expedite the approval process by submitting the PHAST model graphical outputs, Site Plan, P&ID, and Flow diagram along with their AM&M proposal package. The fire AHJ granted the final approval for construction after the Life Safety Inspection was performed by a fire professional fire protection engineer and field inspection was passed after the site visit and within six months of the AM&M application.

2.3 Sunnyvale Hydrogen Fueling Station

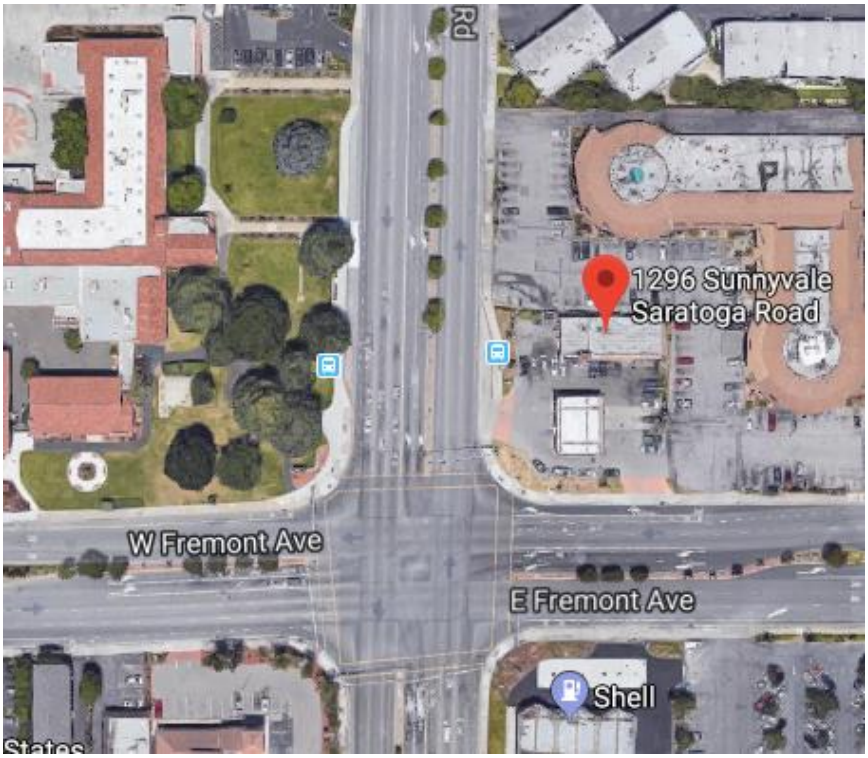

Figure 2.3. Sunnyvale Hydrogen Fueling Station

In Dec 2017, project developers proposed to the City of Sunnyvale adding a hydrogen fueling dispenser and installation of a 369-square foot hydrogen tank enclosure, associated equipment and site improvements to an existing gas station with convenience store.

The site is located at the northeast corner of the intersection of Sunnyvale and Saratoga Roads and Fremont Avenue. Currently, the site is utilized as a gas station and developed with a 2,400-square foot single story convenience store building and fuel canopy with eight fuel pump stations.

The Sunnyvale General Plan designates this site as Village Mixed Use and is zoned as Neighborhood Business/Planned Development. A Special Development Permit (SDP)[4] is required for the proposed auto service station in the Neighborhood Business Zoning district.

The project site is served by a two-way driveway on Sunnyvale - Saratoga Road and another two- way driveway on Fremont Avenue. The site is also served by public transit through an existing Santa Clara Valley Transportation Authority (VTA) bus stop located along the Sunnyvale - Saratoga Road frontage. Surrounding land uses include a retail center and residential uses to the north and east, commercial retail and services to the south and Fremont High School to the west.

From a planning and development perspective, challenges in this project include surrounding land use of a high school campus and day care, potential urban village development in the same lot, potential updated VTA standards on bus access, and landscaping coverage requirement per city design guidelines.

From fire permitting perspective, because the proposed station site is located between an existing VTA bus station and convenience store, near a retail center and residential area, hydrogen venting, particularly cold vapor clouds formation due to venting operation is a concern.

Another challenge the developer faced, in the area of obtaining the fire permit, was meeting the 75 feet separation distance requirement to property lines. Specifically, the applicant is requesting a deviation to allow the proposed hydrogen tank and equipment enclosure to be located within the front yard and provide a 10-foot setback.

A wide array of passive and active safety systems are embedded throughout the proposed hydrogen equipment to provide defense-in-depth protection as AM&Ms such as: reduced number of fittings and valves, use of key welded connections, mechanical ventilation for the Hydrogen Equipment Enclosure (HEE) active Detection, no pressure-building evaporator coils inside LH2 tanks, cone and thread connections, all source valves require 2 separate leak paths, real-time station monitoring and third party listing of NFPA 2 regulated equipment.

The AHJ requested a qualitative risk assessment to be prepared to identify potential on and off-site hazards that may impact adjacent sensitive receptors, such as young children and the elderly. Although the majority of the hazards are similar to common fueling operations, the principal hazards associated with hydrogen facilities are uncontrolled combustion of accidental release of hydrogen.

Furthermore, the AHJ also requested a Worst-Case Scenario Study and the applicant demonstrated that a hydrogen explosion is a low probability event. There is a potential for the tanker to be struck by another vehicle creating a rupture of the delivery truck tank. The potential catastrophic release was modeled utilizing ALOHA[5] software which displayed the flammable area of the vapor cloud, hazard from the ignition of the leaking hydrogen, thermal radiation from the fire and duration of the leakage. ALOHA did not show an off-site consequence that would impact any sensitive receptors. In summary, there will need to be four independent system failures in order for a catastrophic explosion to occur. Even if this explosion does occur, there are deflagration panels that are required that would relieve pressure. All of the design requirements and standards specified in the Risk Assessment and were required for approval from Division of Fire and Environmental Services

Additional documentation such as Fire Plan Check, ALOHA Modeling Outputs, Third Party review and certification by a California Fire PE, Quantitative Risk Assessment, Hazard Analysis, Site Plan, and Fire Prevention Plan were provided along with the permit application.

The AHJ ultimately granted the permit to this application after limiting delivery hours for the hydrogen fuel to the hours of 7:00PM to 6:00AM to avoid potential impacts on students walking to and from school.

2.4 Santa Ana OCTA Hydrogen Fueling Station

Figure 2.4. Santa Ana OCTA Hydrogen Fueling Station

In May 2018, project developers proposed to the Orange County Fire Authority (OCFA) to add a hydrogen fueling station at Orange County Transit Authority (OCTA) Santa Ana Bus Base, which will serve as the future home base for 10 new fuel cell electric transit buses. Developers proposed to build a new hydrogen fueling station including two new hydrogen transit fueling dispensers with flame and gas detection and an installation of a 5000 KG liquid hydrogen tank enclosure, in addition to hydrogen compression, cooling and storage equipment a separate walled equipment yard on the northside of the property line. According

to the project P&ID, one new hydrogen compressor, one new liquid hydrogen storage tank, four new hydrogen vaporizers, one new hydrogen economizer vaporizer, six new hydrogen gas storage vessels, one new hydrogen valve panel, one new chiller, generator connection box, electrical distribution, and PLC controls will be installed in a gated equipment yard.

The site is located at the northwest corner of the OCTA Santa Ana Bus Base on MacArthur Blvd. and the hydrogen dispensers will be installed along-side the existing CNG dispensers under the dispenser island canopy.

Even though this LH2 fueling station is not open to the public, there are still permitting challenges. According to the AHJ, some of the challenges include co-location of CNG station and bus depot/repair facility next to the proposed hydrogen station, and meeting the 75 ft setback distance requirements to property lines and from wall openings, operable openings in buildings and structures per NFPA 2 2016 Edition Section 8.3.2.3.16.

The applicant proposed a wide array of passive and active safety systems as alternative means to meet the prescriptive requirement of the NFPA 2. Some of the AM&Ms proposed include early warning systems such as temperature and pressure sensors in the tanks, fire alarm panel monitored 24/7 at a centralized location and additional E-stops at both the dispenser and the dispensing building. The applicant included documents such as a HazOp[6] Review, Fire Master plan, Fire Alarm Plan, Motor Fuel Dispensing Plan as a part to their permit application to OCFA.

After the Hazop review, the AHJ requested additional hydrogen leak detectors and fire alarms to be included in the design. A Risk Management Plan, Worst Case Scenario Study on a potential H2 Explosion, and California fire PE third party review were requested by the AHJ as a part of the plan review process. The AHJ discussed other risk mitigation strategies such as limiting the time of fueling, limiting time of liquid hydrogen delivery operation and possible partial redesign to allow for additional setback distance to property line. The proposed station is still under permitting process.

3.0 CONCLUSIONS

	AHJ Interviewed	Authority
1	Lynne Kilpatrick, Fire Marshal	City of Sunnyvale Fire Prevention
2	Robert Distaso, Fire Marshal	Orange County Fire Authority
3	Phil Clark, Environmental Health Safety	NREL

Table 2. AHJ's Interviewed on H2 Fueling Station Permitting

Three fire AHJs from various municipalities and agencies with H2 station permitting experience were interviewed. The AHJs might" bench" LH2 station permit applications due to unfamiliarity with hydrogen or the AHJs might request code review from a third-party California licensed professional engineer. Moreover, the California Fire Code incorporates NFPA 2 and the International Fire Code. NFPA 2 2016 Edition has also been directly adopted by the State of California.

For LH2 Station applications, developers have difficulties meeting the 75 feet setback distance requirement for bulk liquid hydrogen storage. AM&Ms are typically proposed as a

part of the permit application package. AM&Ms proposals are often evaluated qualitatively for their efficacy by the AHJs on a case-by case-bases. Additional documentation such as Fire Plan Check, software Modeling Outputs, Third Party review and certification by a CA Fire PE, Quantitative Risk Assessment, Hazard Analysis, Fire Prevention Plan, Fire Master plan, Fire Alarm Plan, and Motor Fuel Dispensing Plan, can significantly expedite the permitting approval process when accompanied as a part of the AM&M proposal to the AHJ.

REFERENCES

1. Conditional Use Permit, Los Angeles County Department of Regional Planning, http://planning.lacounty.gov/faq/cup, 2019.

2. PHAST computer model, US Geological Service, https://www.usgs.gov/software/phast-a-computer-program-simulating-groundwater-flow-solute-transport-and-multicomponent, 2019.

3. USDOT HAZMAT Driver training, US Department of Transportation, https://www.fmcsa.dot.gov/regulations/hazardous-materials/how-comply-federal-hazardous-materials-regulations, 2019.

4. Special Development Permit, County of Sacramento, http://www.per.saccounty.net/Documents/WebsiteForms/Special%20Development%20Permit%20Supplemental%20updated%2007-12-2017_fillable%20form.pdf, 2019.

5. ALOHA Computer Model, US Environmental Protection Agency, https://www.epa.gov/cameo/aloha-software, 2019.

6. HAZOP Review, US Department of Labor, Occupational Safety and Health Administration, https://www.osha.gov/Publications/osha3133.html, 1994.