



Hydrogen Reference Stations for Urban Sites

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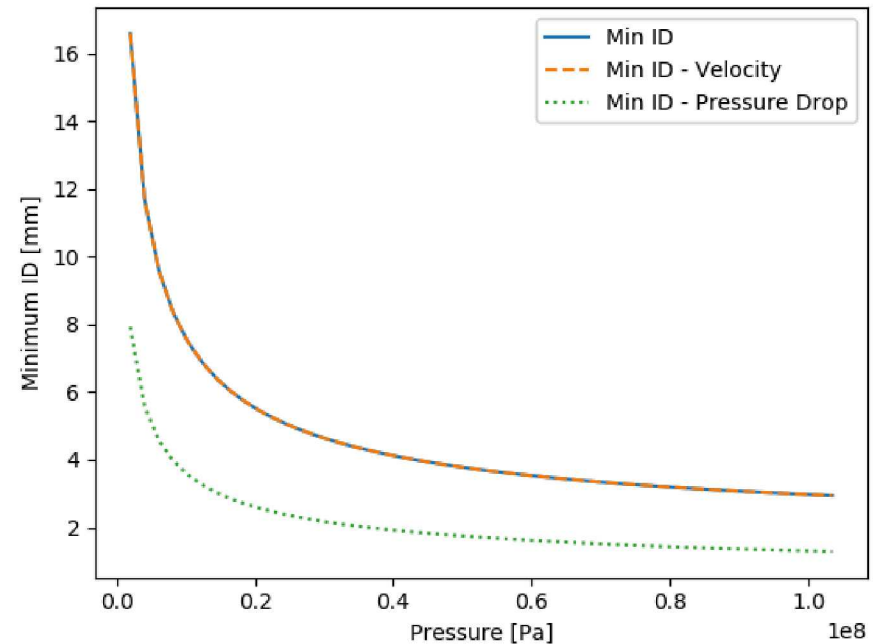
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Building off of previous reference design projects to increase station size and improve station details

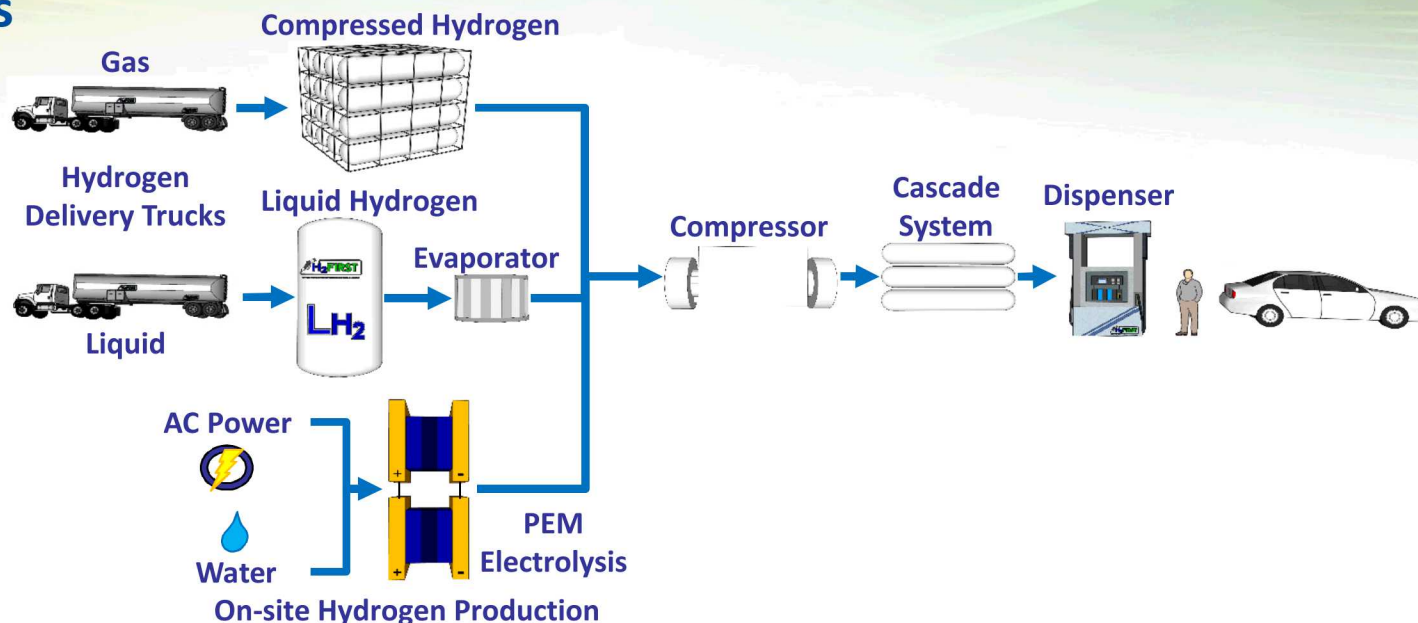
H2USA Hydrogen Fueling Station Working group identified station footprint reduction for urban areas as the *#1 priority* for the FY17 H2FIRST projects

- Analyzing larger station sizes
 - Previous: 300 kg/day, 2 hoses
 - Current: 600 kg/day, 4 hoses
- Level of detail increased
 - Setback distances required by NFPA 2 based on both tube pressure and size



Larger and more detailed system description reveals previously unexplored code requirements

Specified similar component needs for three hydrogen sources



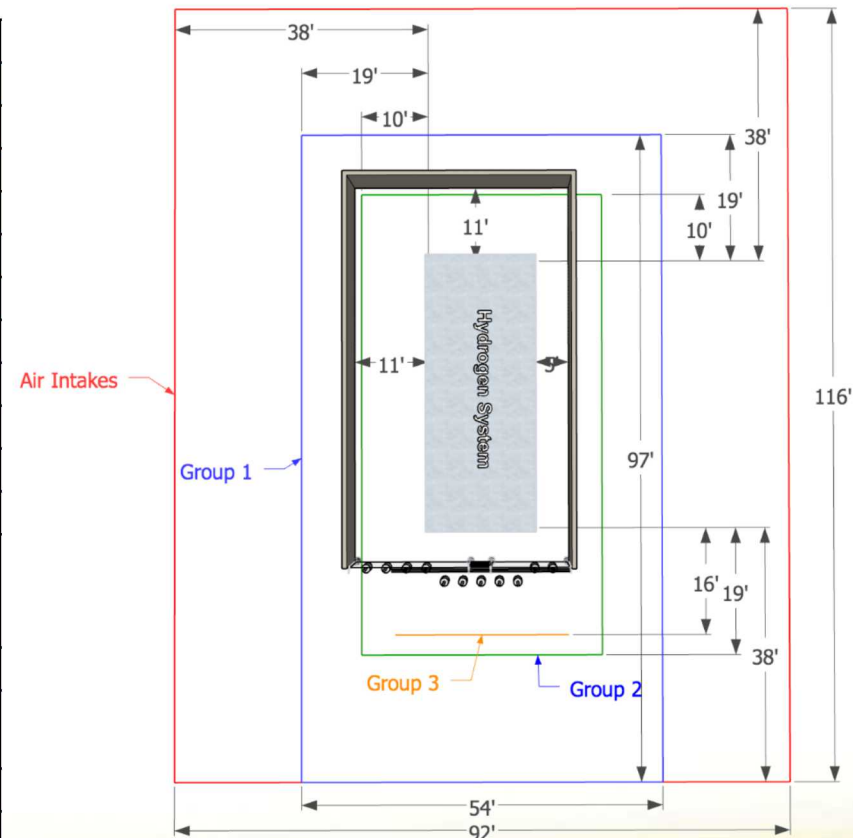
- Compressor
 - 25 kg/hr flow rate (constant 600 kg/day)
 - Outlet pressure of 94.4 MPa (13,688 psi)
- Chillers
 - 25.2 kW (7.2 tons) of refrigeration needed for each chiller
 - Aluminum cooling block of 1,330 kg (0.49 m³) needed for each
- Cascade
 - 10 cascade units, each containing 5 (1:1:3) pressure vessels
 - Outlet flow rate 60 kg/hr to each dispenser
- Dispensing
 - 4 fueling positions, 70 MPa, -40°C

Outdoor bulk gas setback distances give minimum footprint



- Minimum Footprint
 - Hydrogen system only
- Based on pressure and ID of connecting piping

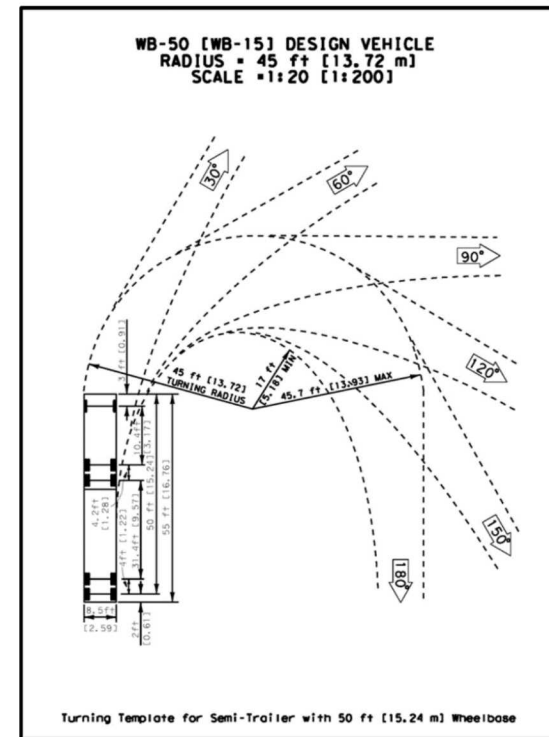
Grp	Description
1	a Lot lines
	b Air intakes (HVAC, compressors, other)
	c Operable openings in buildings and structures
	d Ignition sources such as open flames and welding
2	a Exposed persons other than those servicing the system
	b Parked cars
3	a Buildings of noncombustible non-fire-rated construction
	b Buildings of combustible construction
	c Flammable gas storage systems above or below ground
	d Hazardous materials storage systems above or below ground
	e Heavy timber, coal, or other slow-burning combustible solids
	f Ordinary combustibles, including fast-burning solids such as ordinary lumber, excelsior, paper, or combustible waste and vegetation other than that found in maintained landscaped areas
	g Unopenable openings in building and structures
	h Encroachment by overhead utilities (horizontal distance from the vertical plane below the nearest overhead electrical wire of building service)
	i Piping containing other hazardous materials
	j Flammable gas metering and regulating stations such as natural gas or propane



Different Exposures Have Very Different Setback Distances

Assumptions and considerations:

- Delivery truck path
 - No backing up
 - Non-corner lot (entry and exit on single side of lot)
- Convenience store
 - 50 x 30 ft
- Parking/Traffic Flow
 - C-store parking
 - Fueling positions
 - UT Parking Lot Design Manual
- Kept consistent between designs
- Still idealized system for comparison
 - Other location-specific factors will also have large impact

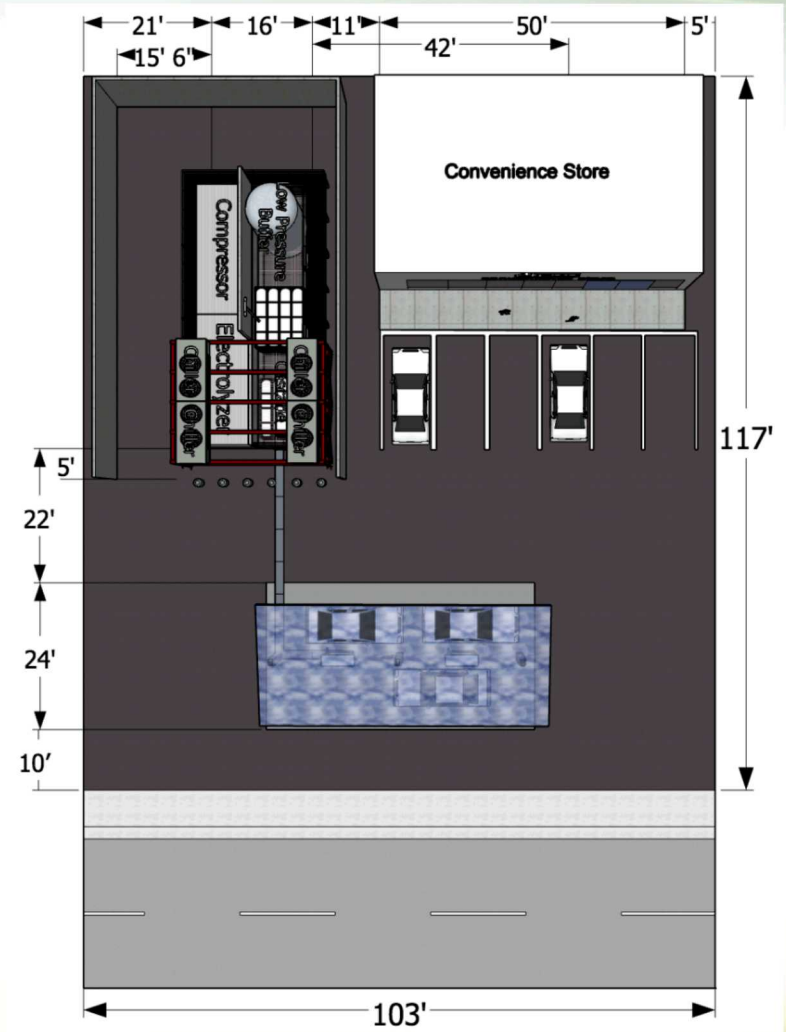


Texas DOT Road Design Manual

Without delivery, base case on-site electrolysis has a small footprint



- PEM electrolyzer (nominal 2 MW)
 - Approximate footprint 40 ft + 20 ft container
 - Supplies 25 kg of GH₂ at 20 bar to compressor
 - Electrolyzer and compressor sized for 24 hour/day use
- GH₂ low pressure buffer (gas reservoir)
 - Used to smooth the flow from the electrolyzer to the compressor.
 - 90 kg of usable hydrogen at full capacity (50 bar)
- No delivery truck
 - Greatly reduces footprint
 - Could reduce resiliency
- Lot Size: 117 x 103 ft
- Total Area: 12,051 ft²



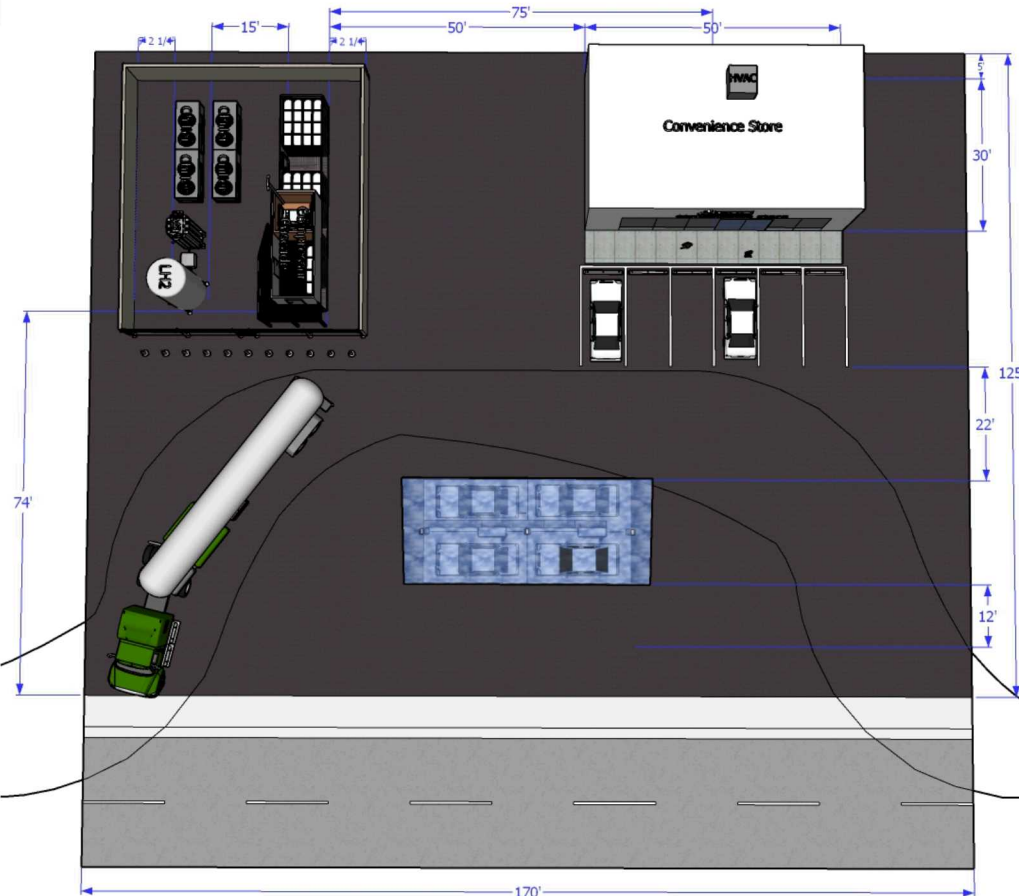
Outdoor bulk liquid setbacks differ significantly from gas



- Based on total amount of bulk liquid hydrogen
 - Not pressure or diameter of piping
- Groups 1, 2, and 3 still exist, but setback distances are not grouped

Exposure	Distance
1 Lot lines *	15 m (50 ft)
2 Air intakes	23 m (75 ft)
3 Operable openings in buildings	23 m (75 ft)
4 Ignition sources	15 m (50 ft)
5 Places of public assembly	23 m (75 ft)
6 Parked cars	1.7 m (25 ft)
7(a)(1) Sprinklered non-combustible building*	1.5 m (5 ft)
7(a)(2)(i) Unsprinklered, without fire-rated wall*	15 m (50 ft)
7(a)(2)(ii) Unsprinklered, with fire-rated wall*	1.5 m (5 ft)
7(b)(1) Sprinklered combustible building*	15 m (50 ft)
7(b)(2) Unsprinklered combustible building*	23 m (75 ft)
8 Flammable gas systems (other than H2)*	23 m (75 ft)
9 Between stationary LH2 containers	1.5 m (5 ft)
10 All classes of flammable and combustible liquids*	23 m (75 ft)
11 Hazardous material storage including LO2*	23 m (75 ft)
12 Heavy timber, coal*	23 m (75 ft)
13 Wall openings	15 m (50 ft)
14 Inlet to underground sewers	1.5 m (5 ft)
15a Utilities overhead: public transit electric wire	15 m (50 ft)
15b Utilities overhead: other overhead electric wire	7.5 m (25 ft)
15c Utilities overhead: hazardous material piping	4.6 m (15 ft)
16 Flammable gas metering and regulating stations	4.6 m (15 ft)

Base case liquid footprint is large due to (non-reducible) 75 ft. setback distance from air intakes



- Bulk liquid storage
 - 800 kg, 11,299 L (2,985 gal)
- Lot size: 170 x 125 ft
- Total Area: 21,250 ft²

Challenges in interpretation and implementation of NFPA 2 were identified



- Gaseous setback distances
 - Large system can have “bulk storage” before and after compressor
- Complexity of system makes selection of single pressure and diameter challenging
 - Single system could take worst-case: maximum pressure from one area and maximum ID from other area
 - Could also calculate setback distances for each system section and select largest
 - This is specified in Appendix I, but nowhere else

Calculations for larger system may lead to unintended setback distances

- Liquid setback distances
 - Hybrid system (liquid-to-gas) analyzed as all-liquid system
 - *Recently changed in 2020 Ed. of NFPA 55*
 - Setback distances are different for most exposures, only a few able to be reduced

Group	Exposure	Reducible	Distance
1	1 Lot lines	*	15 m (50 ft)
1	2 Air intakes		23 m (75 ft)
1	3 Operable openings in buildings		23 m (75 ft)
1	4 Ignition sources		15 m (50 ft)
2	5 Places of public assembly		23 m (75 ft)
2	6 Parked cars		1.7 m (25 ft)
3	7(a)(1) Sprinklered non-combustible building	*	1.5 m (5 ft)
3	7(a)(2)(i) Unsprinklered, without fire-rated wall	*	15 m (50 ft)
3	7(a)(2)(ii) Unsprinklered, with fire-rated wall	*	1.5 m (5 ft)
3	7(b)(1) Sprinklered combustible building	*	15 m (50 ft)
3	7(b)(2) Unsprinklered combustible building	*	23 m (75 ft)
3	8 Flammable gas systems (other than H2)	*	23 m (75 ft)
3	9 Between stationary LH2 containers		1.5 m (5 ft)
3	10 All classes of flammable and combustible liquids	*	23 m (75 ft)
3	11 Hazardous material storage including LO2	*	23 m (75 ft)
3	12 Heavy timber, coal	*	23 m (75 ft)
3	13 Wall openings		15 m (50 ft)
3	14 Inlet to underground sewers		1.5 m (5 ft)
3	15a Utilities overhead: public transit electric wire		15 m (50 ft)
3	15b Utilities overhead: other overhead electric wire		7.5 m (25 ft)
3	15c Utilities overhead: hazardous material piping		4.6 m (15 ft)
3	16 Flammable gas metering and regulating stations		4.6 m (15 ft)

Pending changes to NFPA 2 result in reduced setback distances (and footprints)

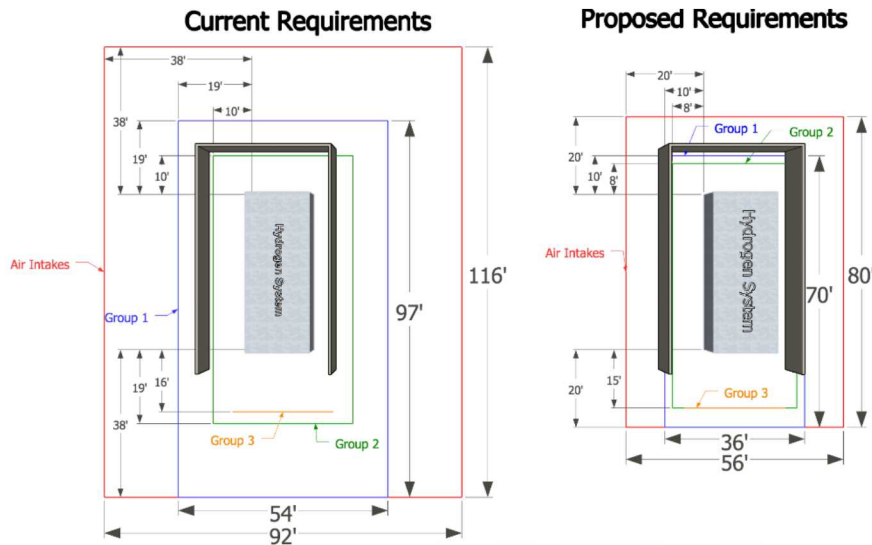


New NFPA

- Effects of future changes to NFPA 2
- Significant impact on minimum footprint, but other factors (traffic and delivery truck path) will likely reduce impact on full layout

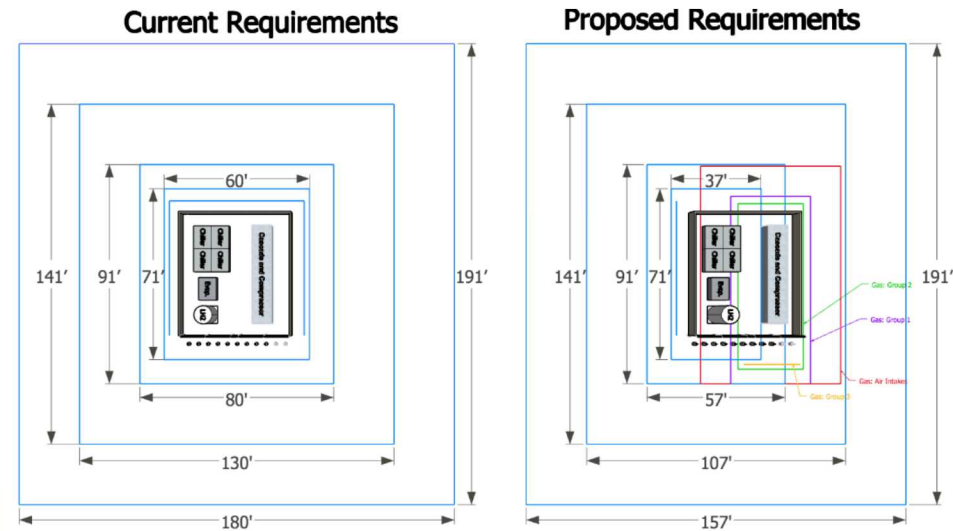
Gaseous System

- Gaseous setback distances re-calculated for 1% pipe area leak instead of 3%



Liquid System

- Gas/liquid hybrid system considered separate

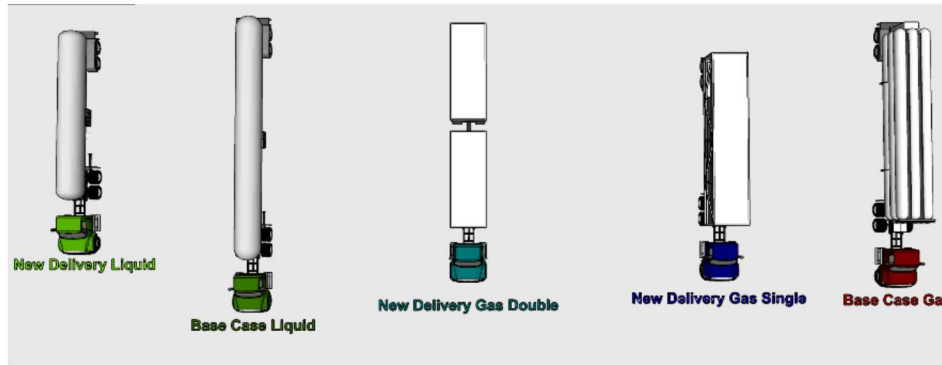


Footprints were developed with alternate delivery trailers and gasoline pumps



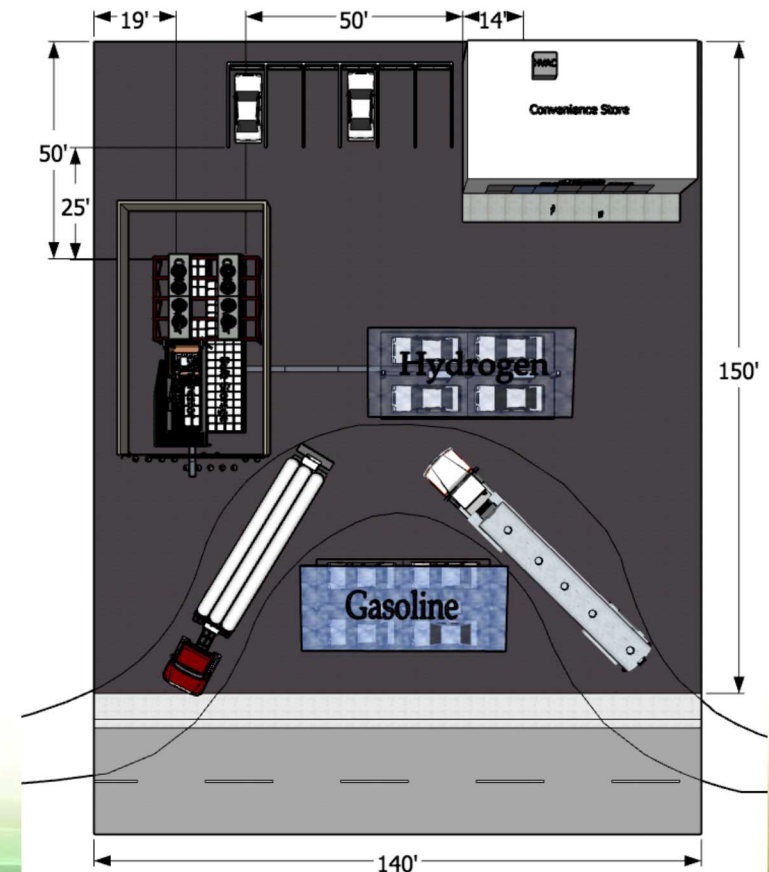
Alternate Delivery

- Smaller delivery trucks greatly reduce footprint
- Higher pressure can maintain delivery capacity



Gasoline Co-Location

- Needs to meet NFPA 2/55 and NFPA 30/30A
- Space for underground gasoline tanks and piping



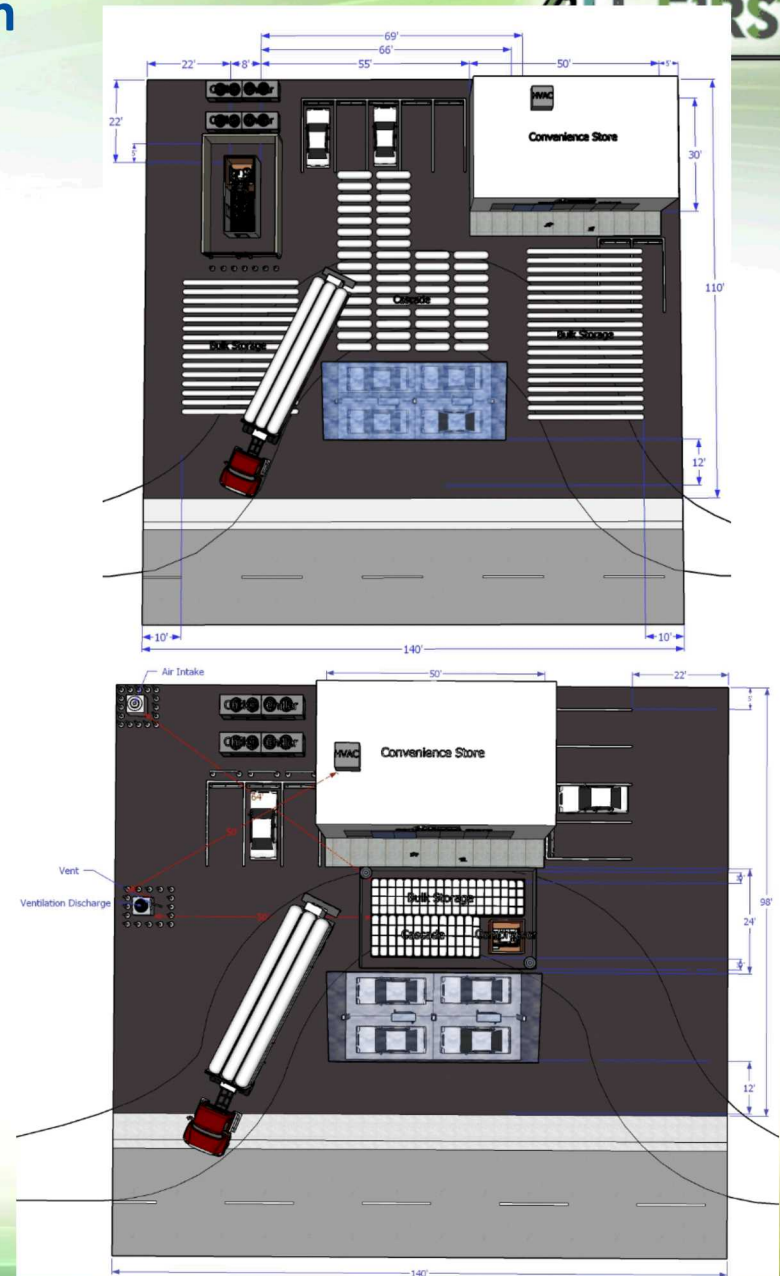
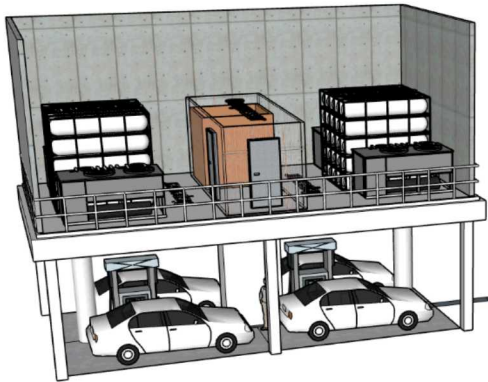
Elevated and underground storage station designs can reduce footprint

Underground Storage

- Direct burial
- Vault

Elevated Storage

- Setback distances still apply line-of-sight
- Storage/equipment on building (e.g., c-store) induce many new and difficult requirements
- Storage and equipment could be ~60 tons
- Seismic loading and aesthetics are issues



Summary of footprints (gaseous storage)



	Total Lot Area (ft ²)	Reduction from Base Case
Base Case Gas	17,640	--
New NFPA Separation Distances	16,240	7.9%
New Delivery Single Truck	14,500	17.8%
New Delivery Double Truck	15,875	10.0%
Gasoline Co-Location	21,000	19.0% (Increase)
Underground Direct-Bury	15,400	12.7%
Underground Vault	13,720	22.2%
Rooftop Storage	16,000	9.3 %

Summary of footprints (liquid storage)



	Total Lot Area (ft ²)	Reduction from Base Case
Base Case Liquid	21,250	--
New NFPA Separation Distances	18,252	14.1%
New Liquid Delivery	17,400	18.1%
Gasoline Co-Location	22,040	3.7% (Increase)
Underground Direct-Bury	15,515	27.0%
Rooftop Storage	19,840	6.63 %

Summary of footprints (on-site generation via electrolysis)



	Total Lot Area (ft ²)	Reduction from Base Case
Base Case	12,051	--
New NFPA Separation Distances	9,180	23.8%
Gasoline Co-Location	21,145	75.5% (Increase)
Rooftop	11,020	8.5%

Stakeholder Workshop Held in Livermore September 2018

Total Attendance: 26



Name	Representation
Brian Ehrhart	Sandia National Laboratories
Gabriela Bran Anleu	Sandia National Laboratories
Ethan Hecht	Sandia National Laboratories
Carl Rivkin	NREL
Jonathan Zimmerman	Sandia National Laboratories
Patricia Gharagozloo	Sandia National Laboratories
Bikram Roy Chowdhury	Sandia National Laboratories
David Farese	Air Products
Jennifer Hamilton	Frontier Energy/CaFCP
Jay Keller	Zero Carbon Energy Solutions
Lucas White	Air Products and Chemicals, Inc
Gerald Hayes	Air Liquide
Lynne Kilpatrick	Sunnyvale Public Safety
James Petrecky	PDC Machines
Reid Larson	Chart Industries
Kevin Harris	Hexagon
Xuefang Li	Shandong University, China
Matt Bray	CARB
Sujin Wren	Hydrogenics Corporation
Sebastian Serrato	California Energy Commission
William Buttner	NREL
Cory Kreutzer	NREL
Lesley Stern	CARB
Edgar Wolff-Klammer	Underwriters Laboratories
Samuel Trompezinski	Air Liquide
Michael Kashuba	GoBiz

Non-prescriptive stations can be approved by the authority having jurisdiction

Performance Based Design NFPA 2 Chapter 5

Scenario
Fire
Pressure Vessel Burst
Deflagration
Detonation
Unauthorized Release
Exposure Fire
External Event
Protection System Out of Service
Emergency Exit Blocked
Fire Suppression Out of Service

Alternate Means and Methods

Specific requirement that is not met is met or mitigated in some alternate way

All other requirements in NFPA 2 are still followed

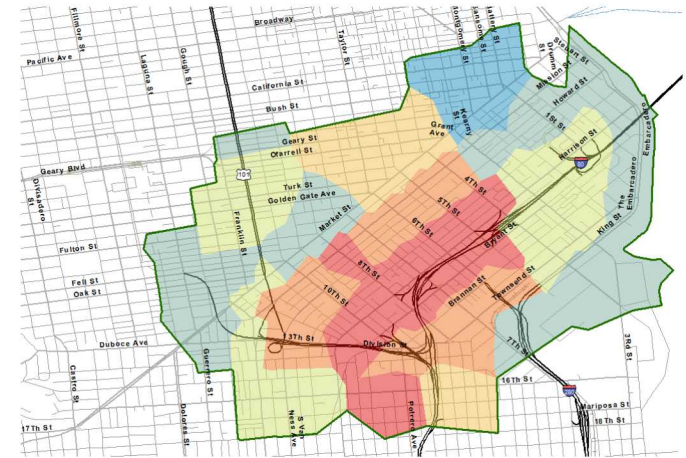
All subsequent requirements in NFPA 2 are not followed

After workshop, we reassessed scenarios to consider for alternative means and methods



- NFPA 2, Annex I lays out methodology for different scenarios for different types of hazards
 - Heat flux of ignited release
 - Overpressure of delayed-ignition release
 - Accumulation of unignited release
- Three examples:
 - Air intakes need to consider unignited concentrations
 - Exposed persons need to consider heat flux
 - Buildings need to consider overpressure
- Heat fluxes used to calculate gaseous setback distances in 2016 and 2020 edition
- Overpressure difficult to assess
 - Leads to “all or nothing” approaches

- Alternate means designs
 - Typically site-specific, but can identify general trends
 - Could help inform future code changes
- Economic evaluation
 - Very location-, time-, and technology-specific
 - Compare cost estimations for changes to footprint reductions
- National siting study for reduced footprint
 - Can quantify effect of varying footprint size
- Prepare final report



TECHNICAL BACK-UP SLIDES

Timeline

- Task start date: March 2017
- Task end date: March 2019

Budget

- FY17 DOE Funding: \$920k
 - SNL: \$870k
 - NREL: \$50k
- Planned FY18 DOE Funding: \$125k
 - SNL: \$100k
 - NREL: \$25k

Barriers (Delivery)

- A. Lack of Hydrogen/Carrier and Infrastructure Options Analysis
- I. Other Fueling Site/Terminal Operations
- K. Safety, Codes and Standards, Permitting


Partners

- NREL

- H2USA Hydrogen Fueling Station Working group identified station footprint reduction for urban areas as the *#1 priority* for the FY17 H2FIRST projects
- Objective:
 - Create compact gaseous and delivered liquid hydrogen reference station designs appropriate for urban locations, enabled by hazard/harm mitigations, near-term technology improvements, and/or risk-informed (performance-based) layout designs

Barrier from Delivery MYRDD	Impact
A. Lack of Hydrogen/Carrier and Infrastructure Options Analysis	Provide assessment of station footprint possibilities using current technologies and show possibilities for urban siting
I. Other Fueling Site/Terminal Operations	Show how to reduce station footprint within or equivalent to current requirements
K. Safety, Codes and Standards, Permitting	Identify main drivers of station footprint and requirements that do not contribute to reduced risk

- H2FIRST itself is a **SNL-NREL** co-led, collaborative project and members of both labs contributed heavily to this project.
- To be as relevant and useful as possible, the project integrates input and feedback from many stakeholders, such as:

- H2USA's Hydrogen Fueling Station Working Group 

- California Fuel Cell Partnership

- California Energy Commission

- California Air Resources Board

- UC Berkeley 

- Argonne National Lab 

- H2 Logic 



- Hydrogenics 

- ITM Power 

- Linde 

- Nuvera 

- PDC Machines 

- Proton OnSite 

- Siemens AG 

- FirstElement 