



## Reference Design of Hydrogen Stations for Urban Sites

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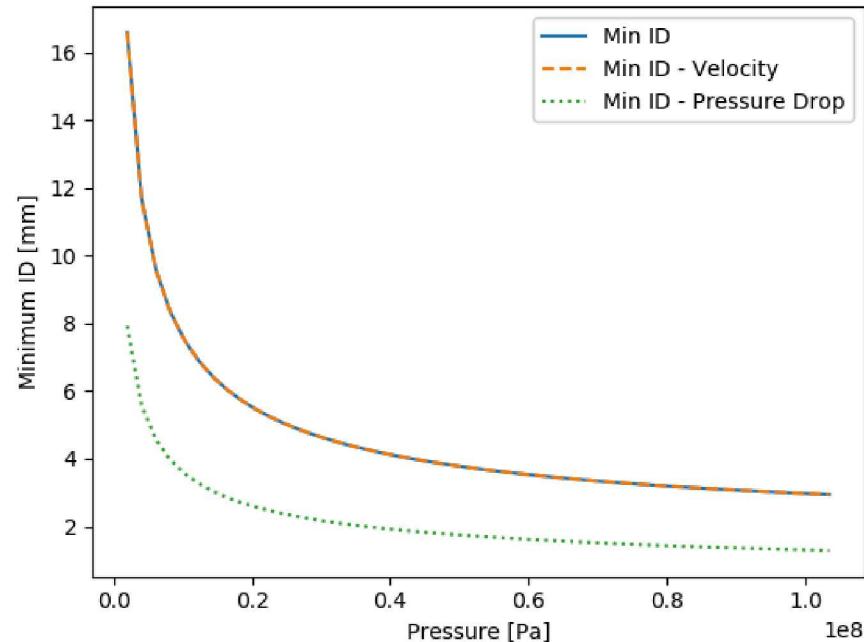
Hydrogen Fueling Infrastructure Research and Station Technology

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



FCTO Target: Reduce footprint of liquid stations by 40% by 2022, relative to 2016 baseline

- 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



*Design of larger and more detailed systems has revealed previously unexplored code requirements.*

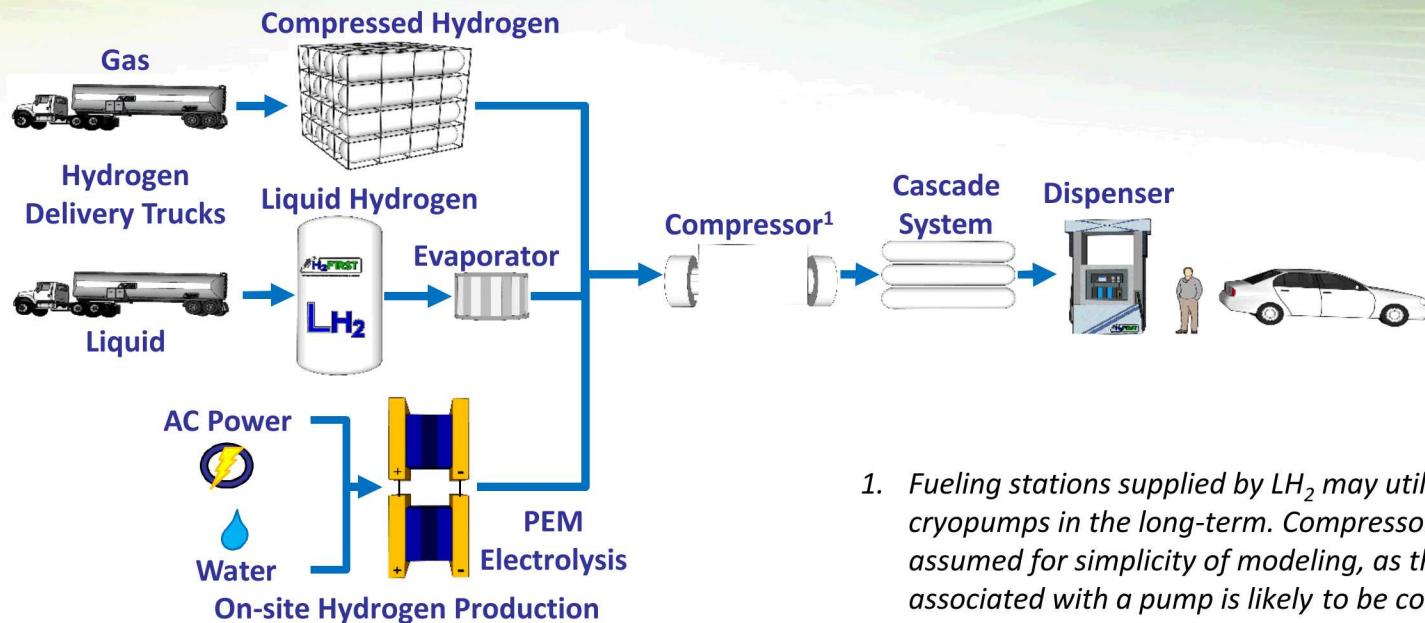


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Hydrogen Fueling Infrastructure Research Station Technology

# Approach: Specified components needed for three methods of hydrogen supply



- 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 m<sup>3</sup>) 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

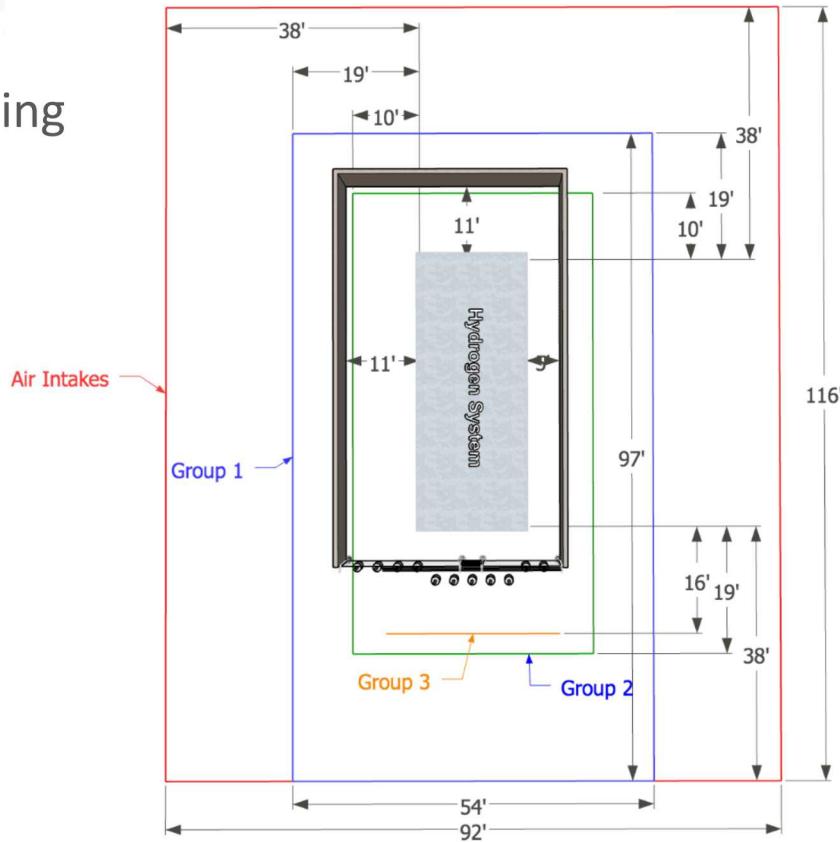


# Outdoor bulk gas setback distances determine minimum footprint



- 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*



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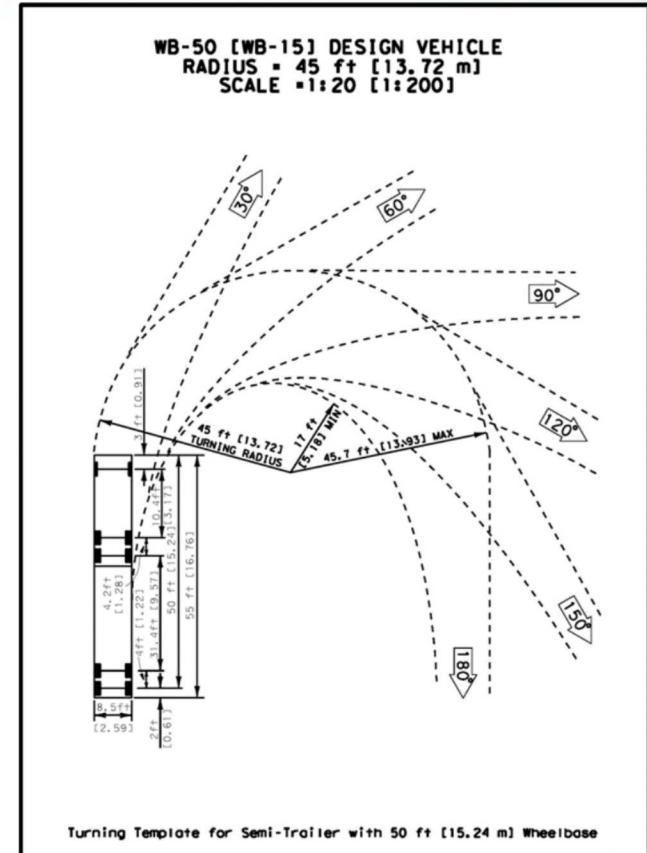
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# Non-hydrogen station components have large impact on footprint



## Assumptions and considerations:

- Delivery truck path
  - Trucks must be capable of turning without reversing
  - Corner lot not considered (entry and exit only on single lot side)
- Convenience store
  - 50 x 30 ft
- Parking/Traffic Flow
  - Convenience store parking
  - Fueling positions
  - UT Parking Lot Design Manual
- Kept consistent between designs
- System was idealized for comparison
  - Other location-specific factors will also have large impact on footprint



Texas DOT Road Design Manual

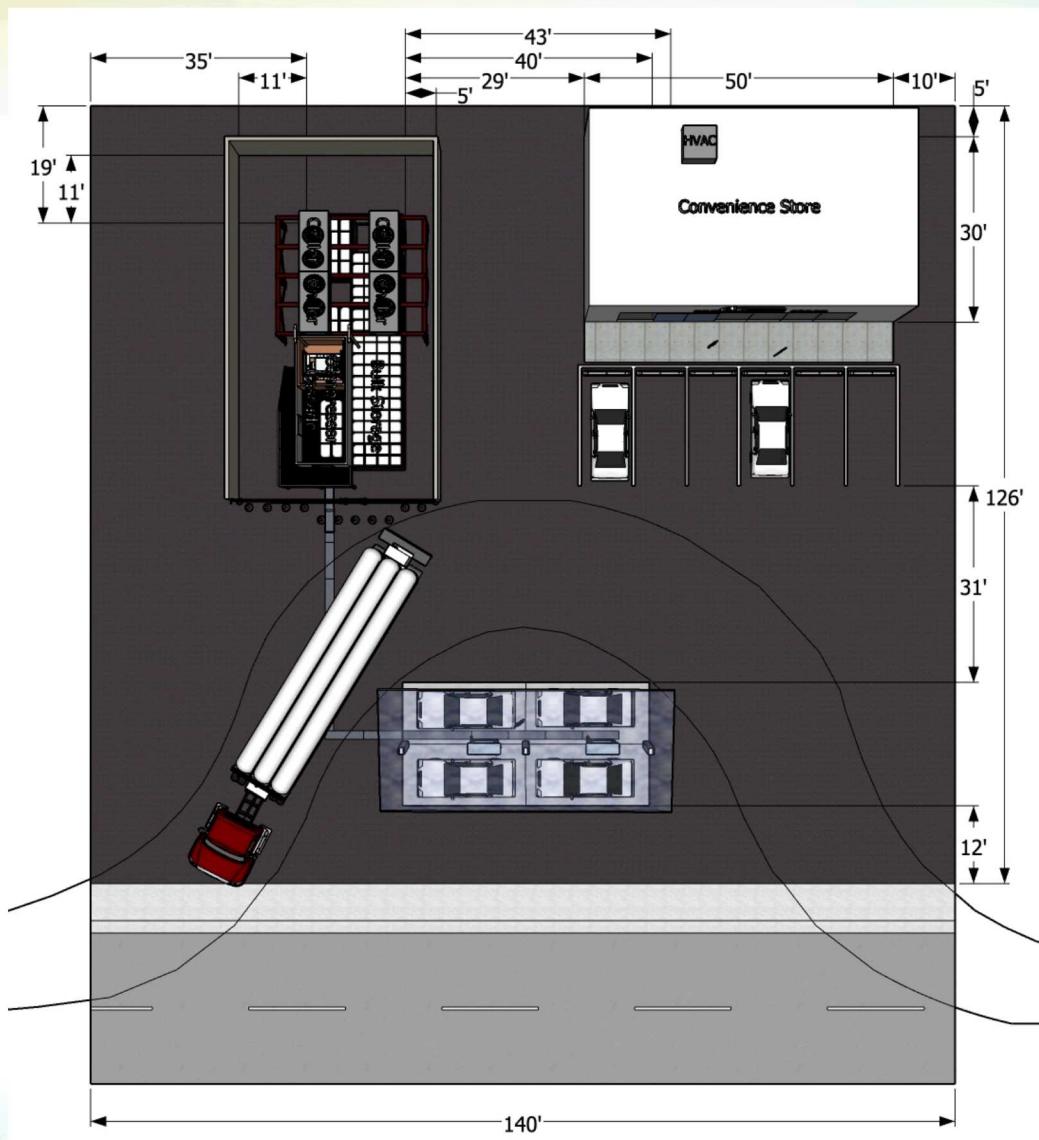


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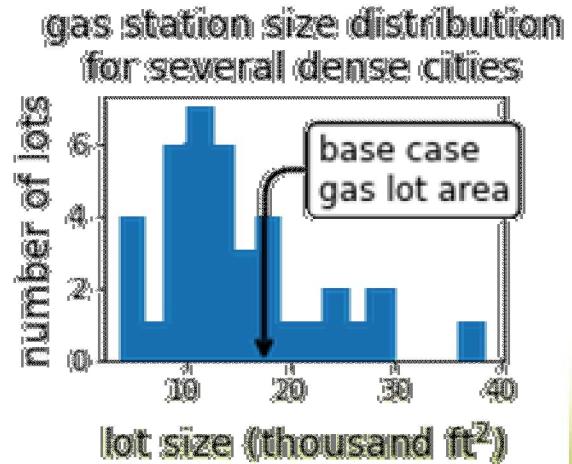
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## Base Case Gas: Delivery truck path (rather than setback distances) extends lot in two dimensions



- Lot Size: 126 x 140 ft
- Total Area: 17,640 ft<sup>2</sup>

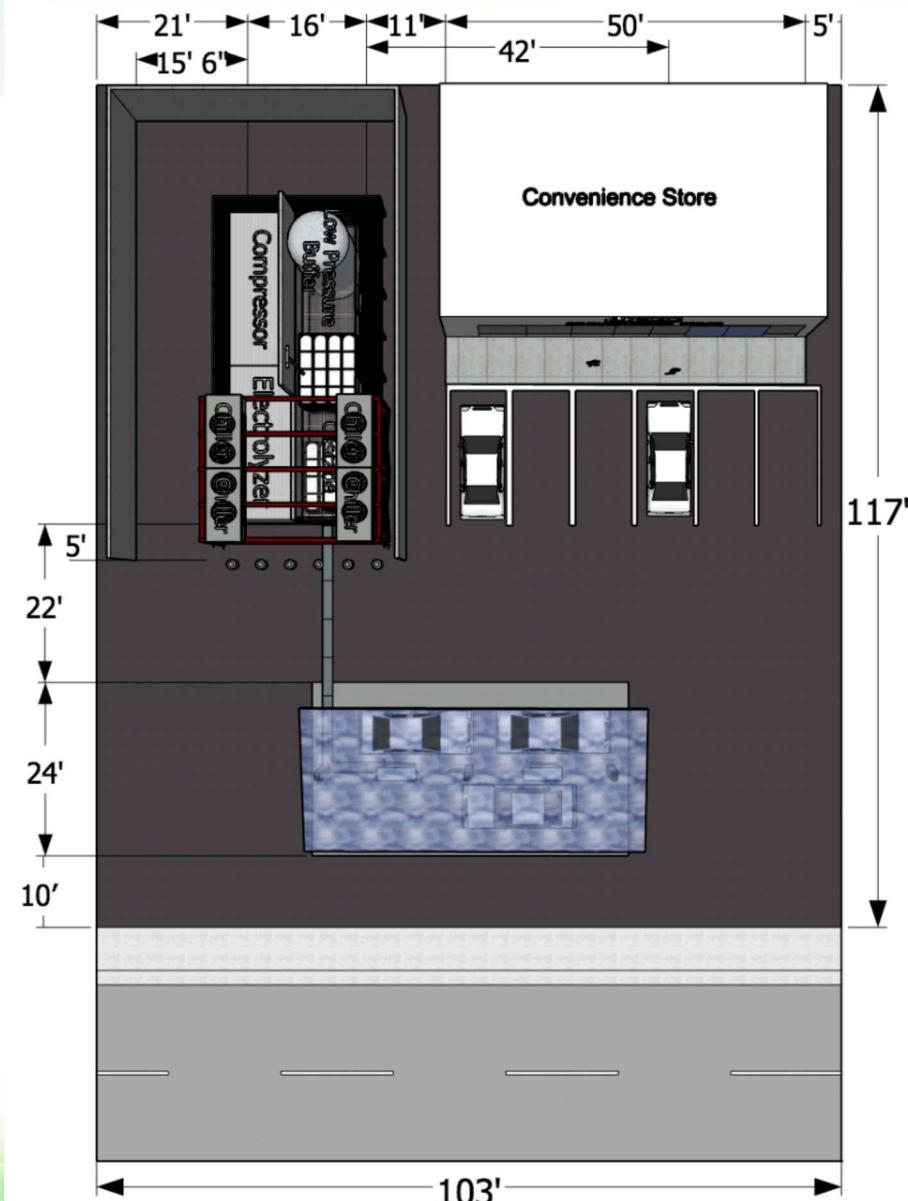
*(Slightly larger than median of [small sample of] existing urban gas stations)*



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



- PEM electrolyzer (nominal 2 MW)
  - Approximate footprint 40 ft + 20 ft container
  - Supplies 25 kg of GH<sub>2</sub> at 20 bar to compressor
  - Electrolyzer and compressor sized for 24 hour/day use
- GH<sub>2</sub> 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
    - No direct way to delivery emergency hydrogen if electrolyzer is down
- Lot Size: 117 x 103 ft
- Total Area: 12,051 ft<sup>2</sup>



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# Outdoor bulk liquid setbacks differ significantly from gas

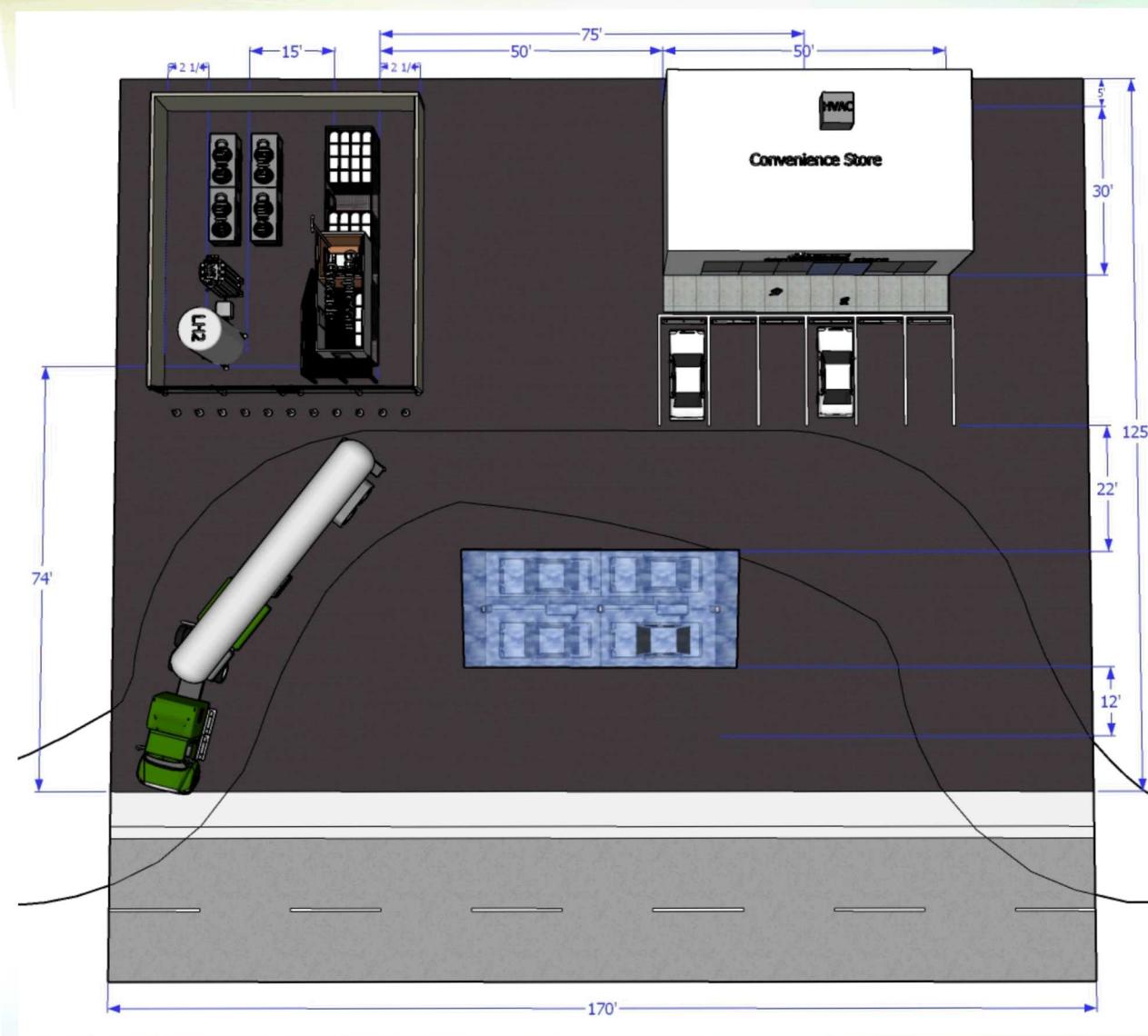


- Based on total amount of bulk liquid hydrogen
  - Not pressure or diameter of piping
- Groups 1, 2, and 3 still exist, but setback distances are not grouped

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 H <sub>2</sub> )*	23 m (75 ft)
9 Between stationary LH <sub>2</sub> containers	1.5 m (5 ft)
10 All classes of flammable and combustible liquids*	23 m (75 ft)
11 Hazardous material storage including LO <sub>2</sub> *	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 ft<sup>2</sup>



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# 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	Yes	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)
2	5 Places of public assembly		23 m (75 ft)
	6 Parked cars		1.7 m (25 ft)
3	7(a)(1) Sprinklered non-combustible building	Yes	1.5 m (5 ft)
	7(a)(2)(i) Unsprinklered, without fire-rated wall	Yes	15 m (50 ft)
	7(a)(2)(ii) Unsprinklered, with fire-rated wall	Yes	1.5 m (5 ft)
	7(b)(1) Sprinklered combustible building	Yes	15 m (50 ft)
	7(b)(2) Unsprinklered combustible building	Yes	23 m (75 ft)
	8 Flammable gas systems (other than H <sub>2</sub> )	Yes	23 m (75 ft)
	9 Between stationary LH <sub>2</sub> containers		1.5 m (5 ft)
	10 All classes of flammable and combustible liquids	Yes	23 m (75 ft)
	11 Hazardous material storage including LO <sub>2</sub>	Yes	23 m (75 ft)
	12 Heavy timber, coal	Yes	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)



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

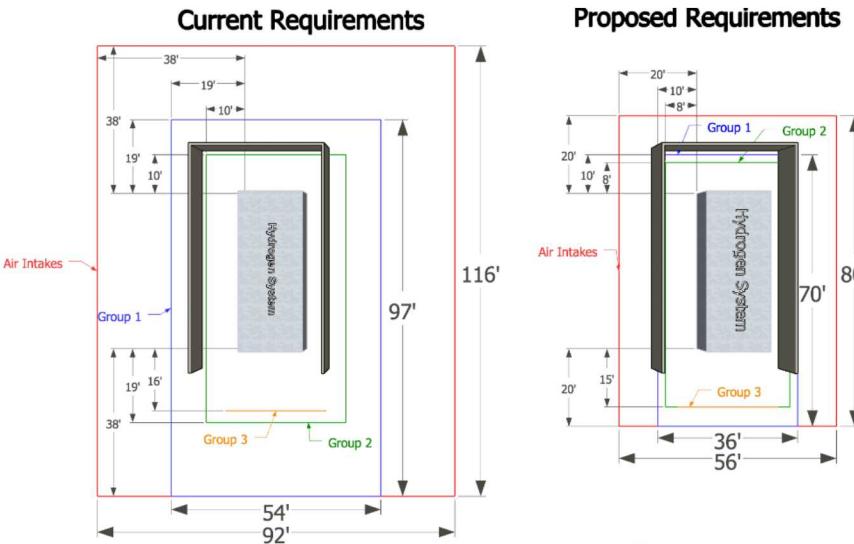


## Effects of future changes to NFPA 2

- Significant impact on minimum footprint, but other factors (traffic and delivery truck path) will reduce impact on full layout

### Gaseous System

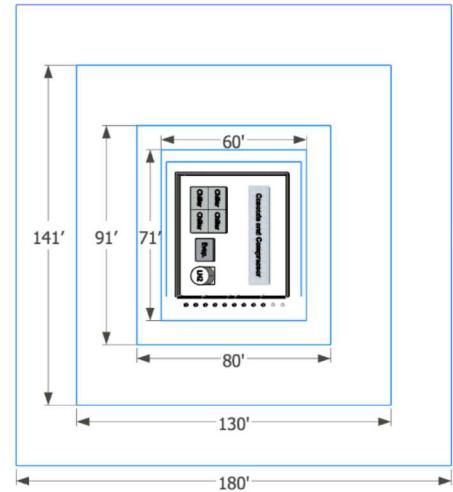
- Gaseous setback distances re-calculated for 1% pipe area leak instead of 3%



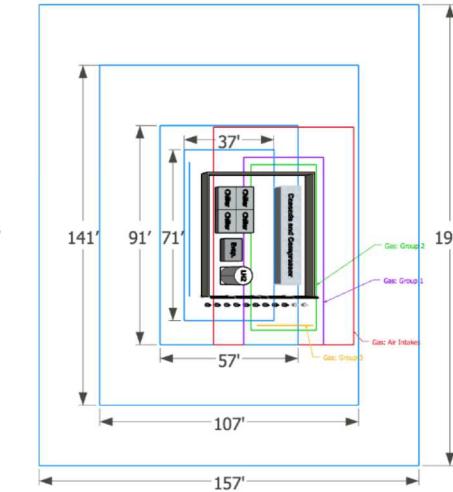
### Liquid System

- Gas/liquid hybrid system considered separate

### Current Requirements



### Proposed Requirements

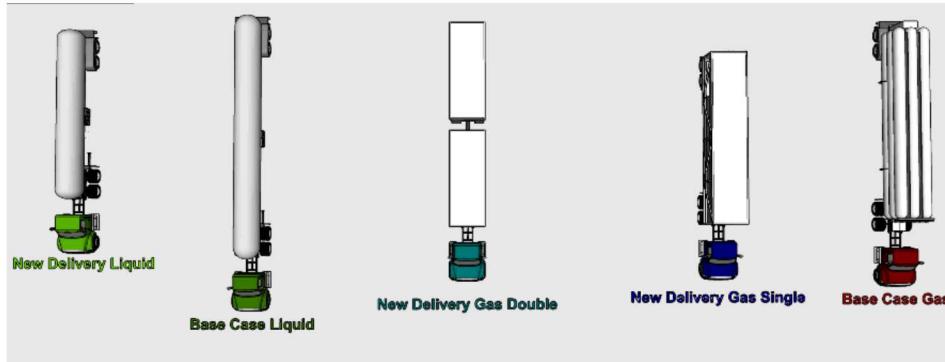


# Footprints were developed with alternate delivery trailers and gasoline pumps



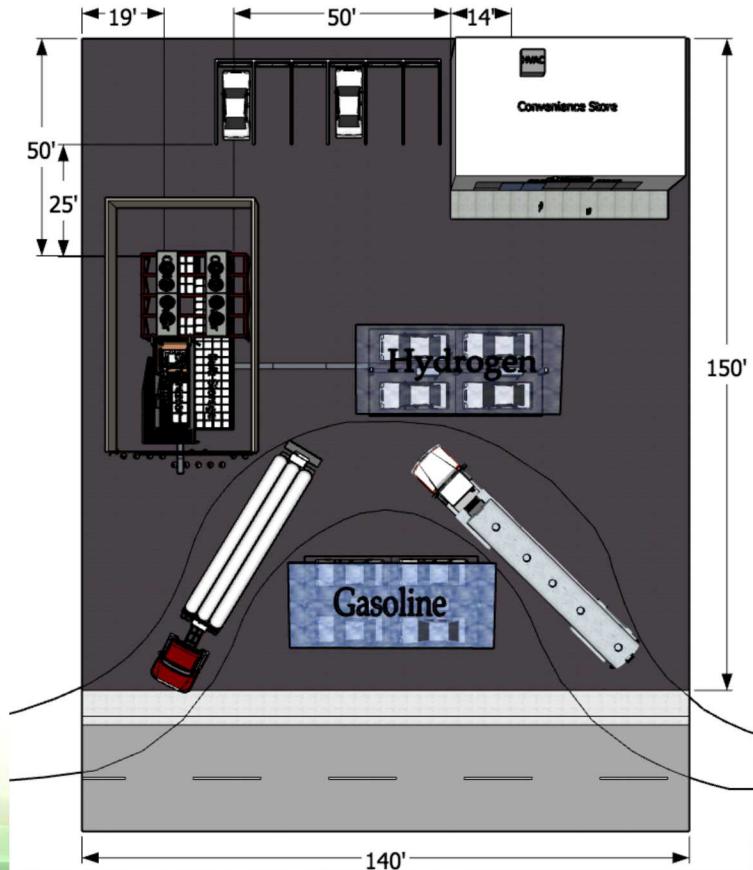
## Alternate Delivery

- 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



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# Elevated and underground storage station designs can reduce footprint

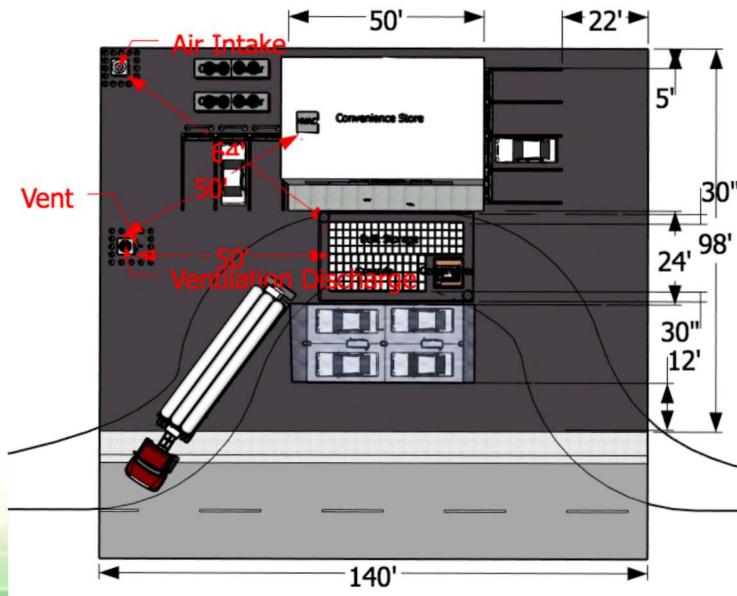
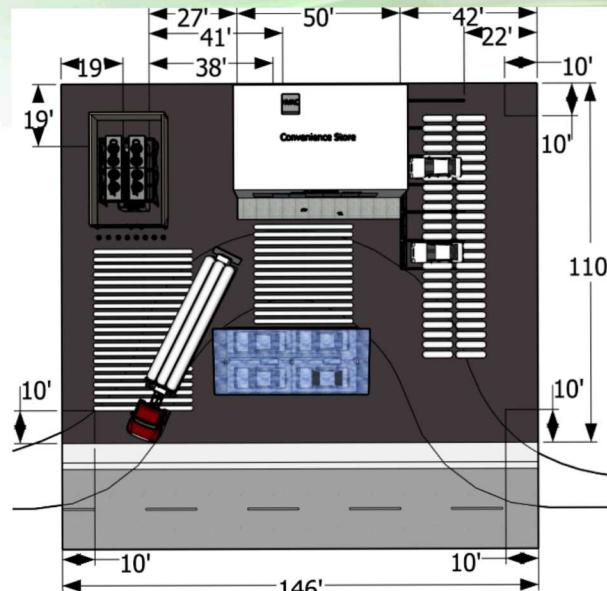
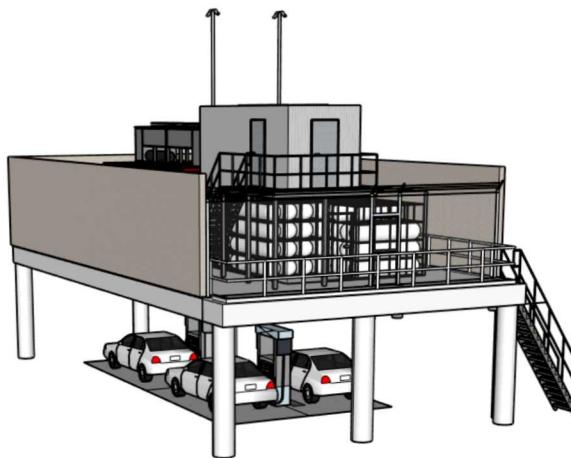


## Underground Storage

- Direct burial
- Vault

## Elevated Storage

- Setback distances still apply to line-of-sight
- Storage/equipment on building (e.g., convenience store) induce many new and difficult requirements
- Storage and equipment could be ~140 tons
- Seismic loading and aesthetics are issues



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## Summary of footprints (gaseous storage)



	Total Lot Area (ft <sup>2</sup> )	Reduction from Base Case
Base Case Gas	17,640	--
New NFPA Separation Distances	17,640	0.00%
New Delivery Single Truck	14,391	18.42%
New Delivery Double Truck	15,875	10.01%
Gasoline Co-Location	21,980	-24.60% (Increase)
Underground Direct-Bury	16,060	8.96%
Underground Vault	13,720	<b>22.22%</b>
Rooftop Storage	15,400	12.70%

*Gasoline co-location lot size increases due to  
additional gasoline dispensers  
Underground vault has largest size reduction*



## Summary of footprints (liquid storage)



	Total Lot Area (ft <sup>2</sup> )	Reduction from Base Case
Base Case Liquid	21,250	0.00%
New NFPA Separation Distances	18,252	14.11%
New Liquid Delivery	19,080	10.21%
Gasoline Co-Location	25,330	-19.20% (Increase)
Underground Direct-Bury	15,515	<b>26.99%</b>
Rooftop Storage	19,840	6.63 %

*Underground vault not available for bulk liquid storage, but direct-bury has largest size reduction*



	Total Lot Area (ft <sup>2</sup> )	Reduction from Base Case
Base Case	14,756	0.00%
New NFPA Separation Distances	<b>11,934</b>	<b>19.12%</b>
Gasoline Co-Location	21,980	-48.96% (Increase)
Underground Direct-Bury	13,340	9.60%
Underground Vault	16,240	-10.06% (Increase)
Rooftop Storage	11,466	22.30%

*Rooftop storage has smallest possible footprint, but may not be feasible*

*On-site production with updated NFPA 2 setback distances and no delivery truck path has smallest overall lot size*

# Approximated potential to site stations in dense urban areas



## Siting results on delivered gas designs

- Cities in five states (CA, CT, MD, MA, NY) were selected
- Total of 40 gasoline stations in these cities were analyzed
  - Located using Google Maps
- The lot size ( $\text{ft}^2$ ) of each station was obtained from county property tax records
- The lot size was compared to generic station designs
- The number of available stations that can be converted into hydrogen stations were identified

*Illustrates potential effect  
of reduction in lot sizes*

	Lot Area ( $\text{ft}^2$ )	Reduction from Base Case	Lot available (out of 40) [%]
Base Case Gas	17,640	--	12 [30%]
New NFPA Separation Distances	17,640	0.00%	12 [30%]
New Delivery Single Truck	14,391	18.42%	16 [40%]
New Delivery Double Truck	15,875	10.01%	16 [40%]
Gasoline Co- Location	21,980	-24.60% (increase)	8 [20%]
Underground Direct-Bury	16,060	8.96%	16 [40%]
Underground Vault	13,720	22.22%	18 [45%]
Rooftop Storage	15,400	12.70%	16 [40%]



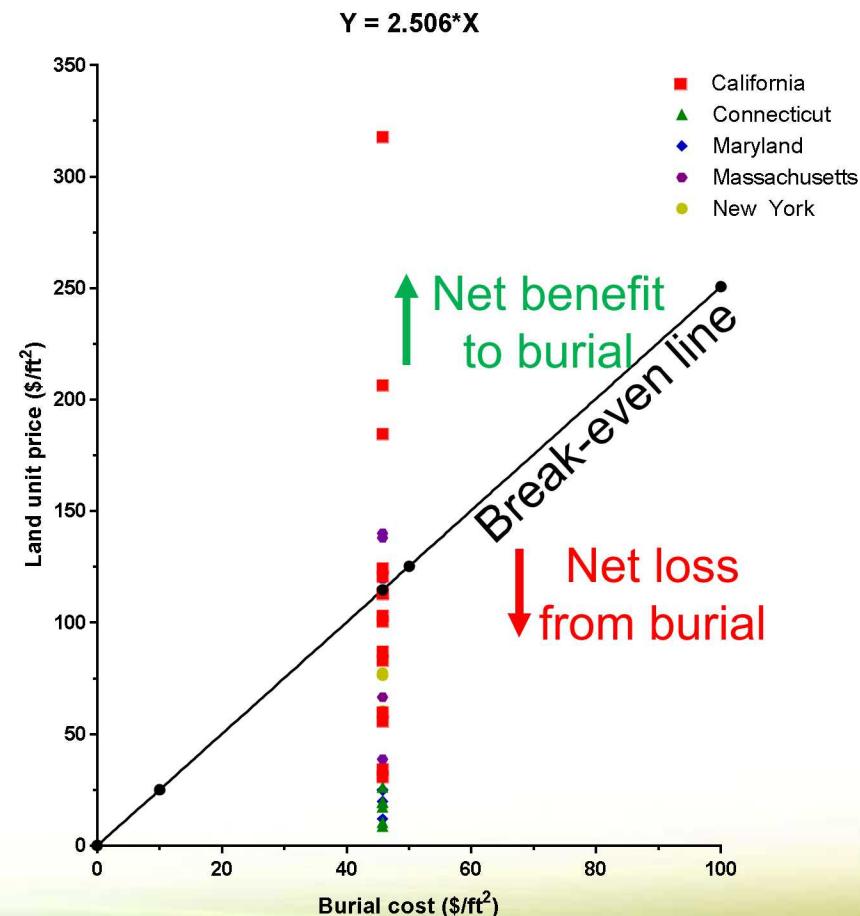
# Demonstrated economic impact of station design changes (with special consideration for underground)



- Same 40 gasoline stations analyzed
- The land unit price (\$/ft<sup>2</sup>) calculated by the land price and lot size obtained from county property tax record
- Underground direct-bury cost estimated from underground propane tank installation cost: **\$45.8/ft<sup>2</sup>**
- Slope of break-even line determined by ratio of burial area for each design and the difference of lot size between base case and underground burial designs
- Multiple possible burial costs considered to show sensitivity vs land unit price

*Illustrates potential economic  
trade-off of design change  
relative to base case*

Gaseous hydrogen  
underground direct-bury



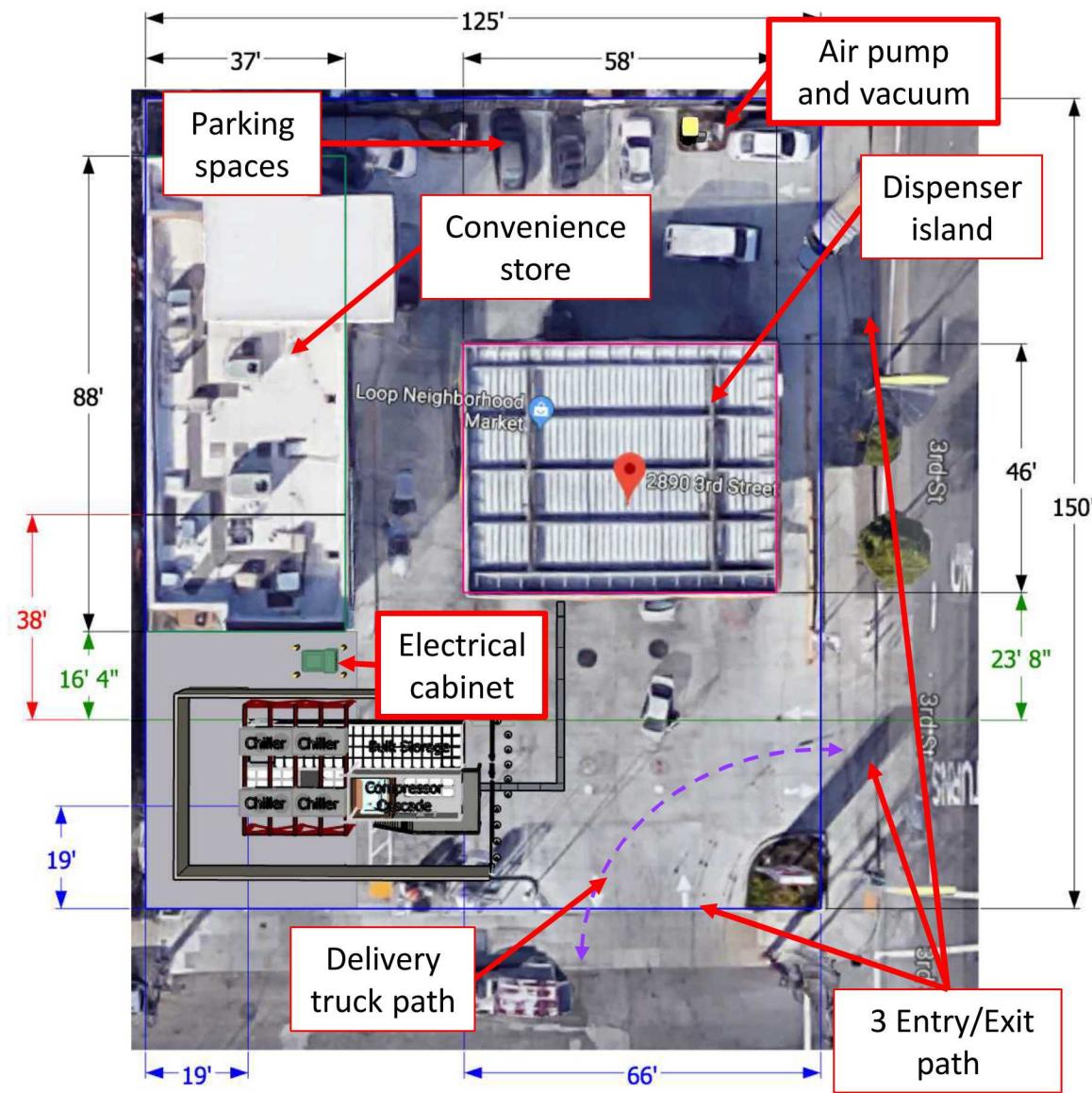
# Performed real station co-location case study to show impact of site-specific features



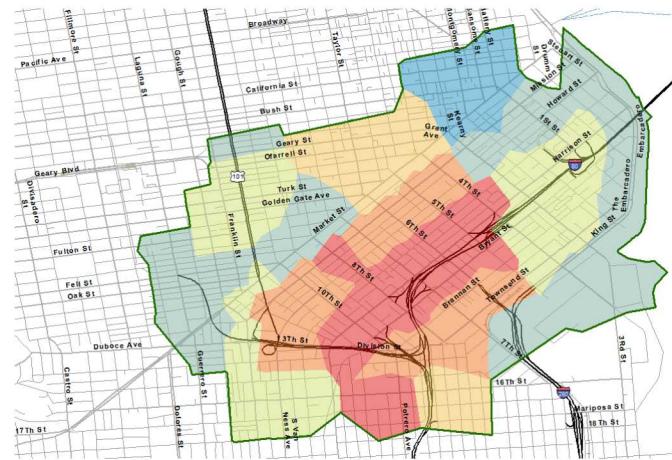
- San Francisco station on a corner
  - Delivery truck path is simplified
- One vehicle entry/exit blocked by hydrogen system
  - Still has 3 remaining
- Electrical cabinet was moved
- Air intakes on roof of convenience store would have to be moved
  - Must be 38 feet from hydrogen system

	SF Site Colocation	Generic Co-location
Lot Size	18,000 ft <sup>2</sup>	21,000 ft <sup>2</sup>
Convenience store size	3,256 ft <sup>2</sup>	1,500 ft <sup>2</sup>
Dispenser island	2,668 ft <sup>2</sup>	1,600 ft <sup>2</sup>

*Real-world locations will differ from generic designs*



- Remainder of FY19
  - Finalize siting study, and economic comparisons
  - Make reduced footprint designs based on alternate means
  - Prepare final report
- Potential Future Work
  - Incorporation of standardized alternative means into safety codes and standards
  - Exploration of underground burial safety code requirements and justifications



Thank you!

## QUESTIONS?



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## TECHNICAL BACK-UP SLIDES

# Stakeholder feedback solicited from:



Name	Representation
Kyle McKeown	Linde
Amgad Elgowainy	Argonne National Laboratory
Michael Ciotti	Linde
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



- 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

## After stakeholder feedback, 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



# Collaborations



- 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 **H2USA**



- 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



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*

## Alternative means



- Determine what performance criteria is applicable to each exposure.
  - NFPA 2 Annex I Table I.2(c) and (d) were used to determine the performance criteria and the hazardous material scenario
- Get numerical values that can be used to determine the separation distances for each exposure
  - Heat flux
  - Hydrogen flammable concentrations
  - Frequency of fatalities

Exposure	Heat flux	Notes
Personnel	1,577 W/m <sup>2</sup>	Threshold to which personnel with appropriate clothing can be continuously exposed. Used as the “no harm” value.
Personnel	4,732 W/m <sup>2</sup>	Threshold for exposure to employees for a maximum of 3 minutes.
Combustible materials	20,000 W/m <sup>2</sup>	Minimum heat flux for the nonpiloted ignition of combustible materials, such as wood.
Non-combustible materials	25,237 W/m <sup>2</sup>	Threshold heat flux imposed by the International Fire Code for noncombustible materials.

