SAND2019-13037C

H2FIRST

Hydrogen Fueling Infrastructure Research and Station Technology

# Comparisons of Design Changes on Footprint of Hydrogen Refueling Stations for Urban Sites

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# Background: Hydrogen Vehicle Fueling Infrastructure

- Past and current hydrogen refueling stations in California have capacities of 350 kg/day (or less)
  - Higher capacity stations needed to meet increasing demand
- Past stations with liquid hydrogen (LH2) storage range from 30,000 to >100,000 $ft^2$
  - Urban locations require much smaller footprints

- **DOE FCTO Target: Reduce footprint of liquid stations by 40% by 2022, relative to 2016 baseline**
- Objective:
  - Create compact gaseous and liquid hydrogen reference station designs appropriate for urban locations, enabled by design changes and near-term technology and fire code changes

# Approach: Develop base cases and assess relative impact of non-compliance/technology improvements

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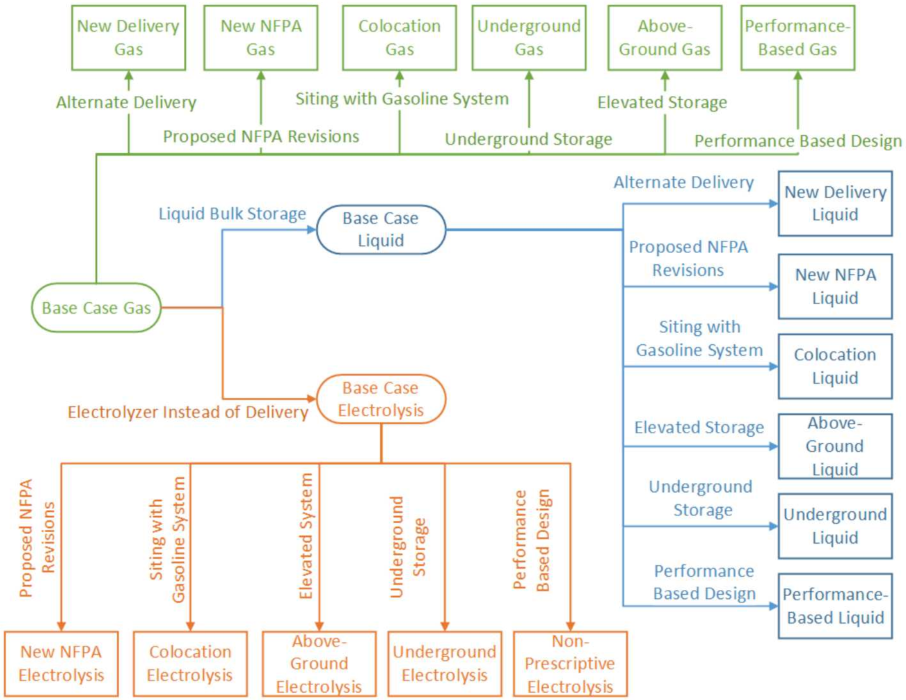
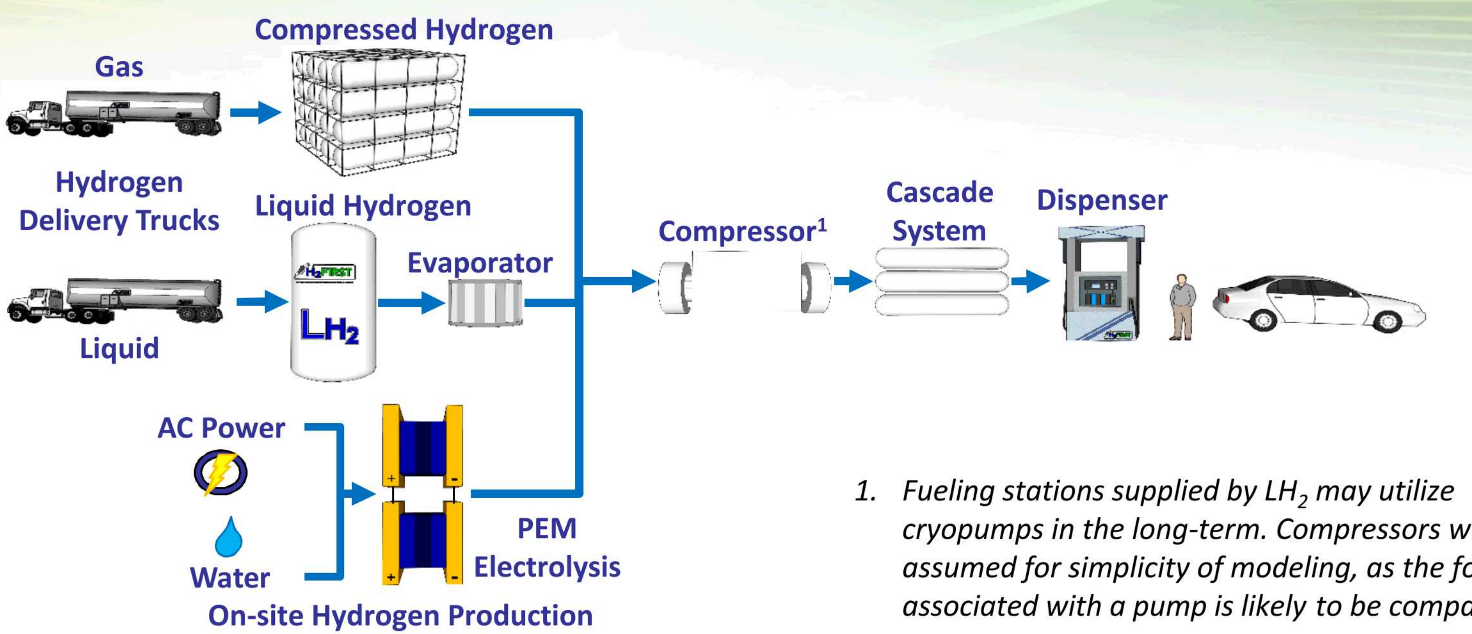
- Focus on **reducing station footprint**
  - Previous reference station analyses focused on system layout, physical footprint, and cost
- Simplified, generic, rectangular stations
  - All requirements and setback distances met
- Make **comparisons** to base case designs for
  1. Delivered gas,
  2. Delivered liquid, and
  3. On-site production via electrolysis
- Assess the impact of:
  - New code requirements
  - New delivery methods
  - Gasoline refueling station co-location
  - Underground storage
  - Roof-top storage
  - Performance-based designs



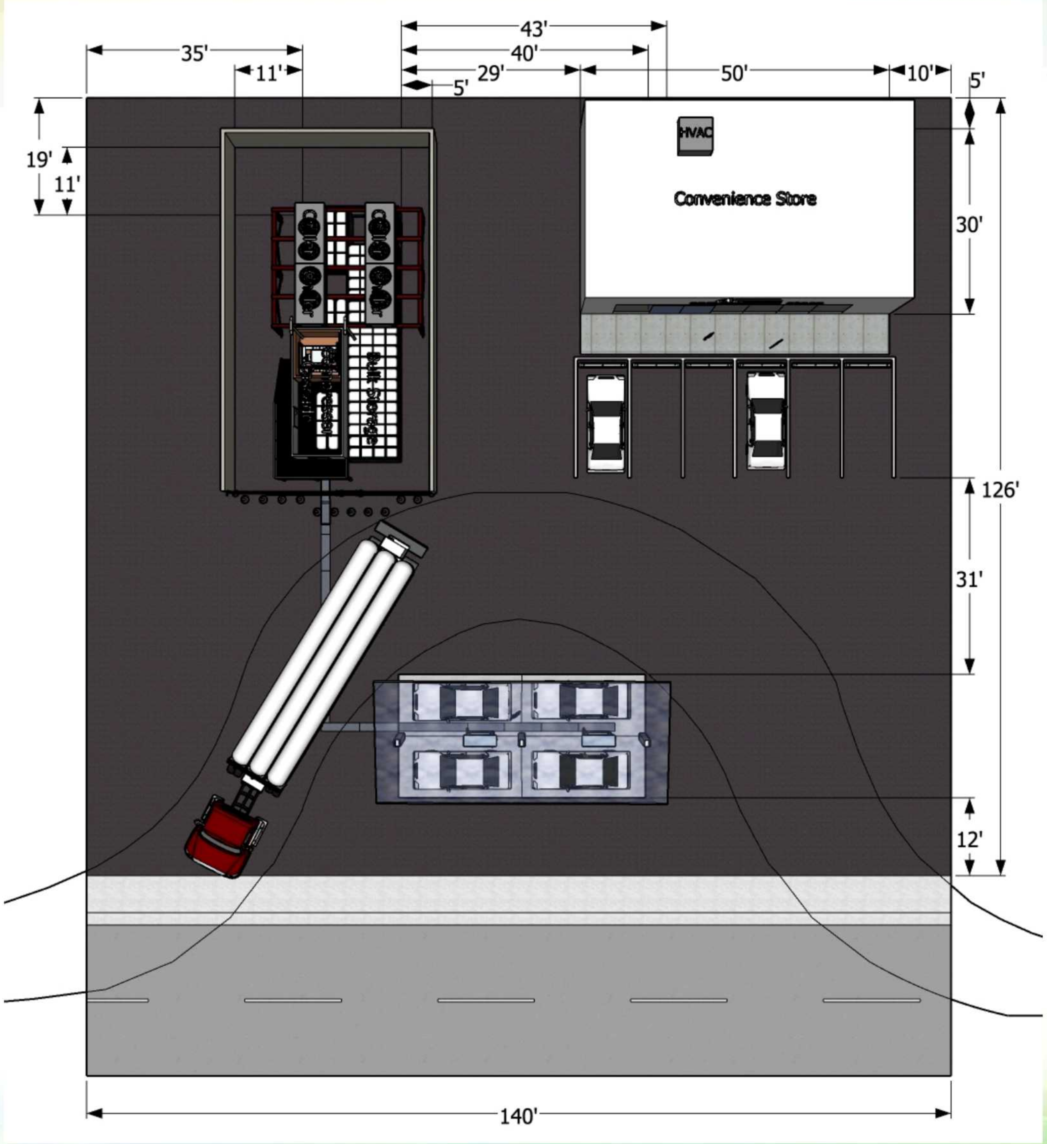
# Specified components needed for three methods of hydrogen supply




1. *Fueling stations supplied by $LH_2$ may utilize cryopumps in the long-term. Compressors were assumed for simplicity of modeling, as the footprint associated with a pump is likely to be comparable.*

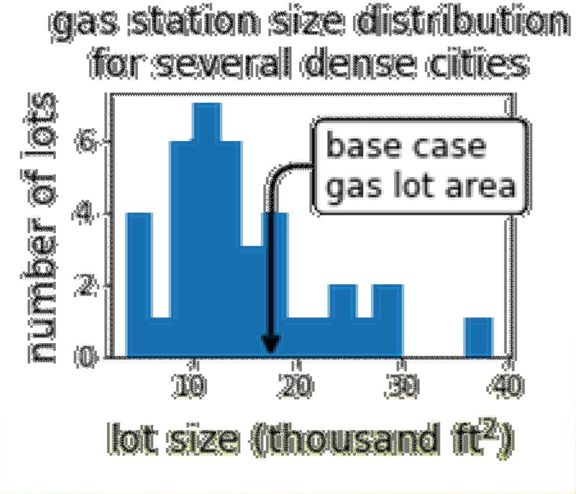
- Compressor
  - 25 kg/hr flow rate (constant 600 kg/day)
  - Outlet pressure of 94.4 MPa (13,688 psi)
- Chillers
  - 25.2 kW (7.2 tons) of refrigeration needed for each chiller
  - Aluminum cooling block of 1,330 kg (0.49 $m^3$) needed for each
- Cascade
  - 10 cascade units, each containing 5 (1:1:3)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

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



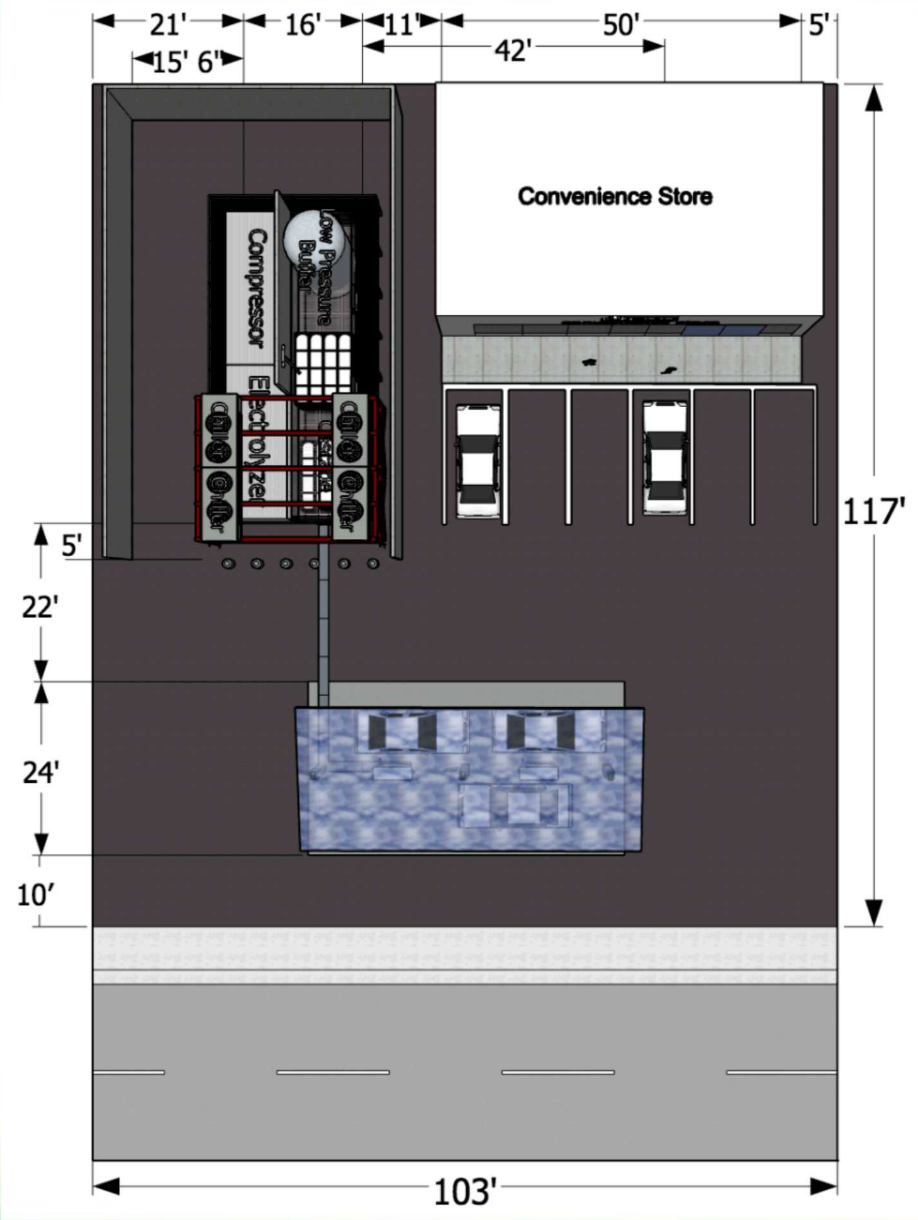

- Lot Size: 126 x 140 ft
- Total Area: 17,640 $ft^2$

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

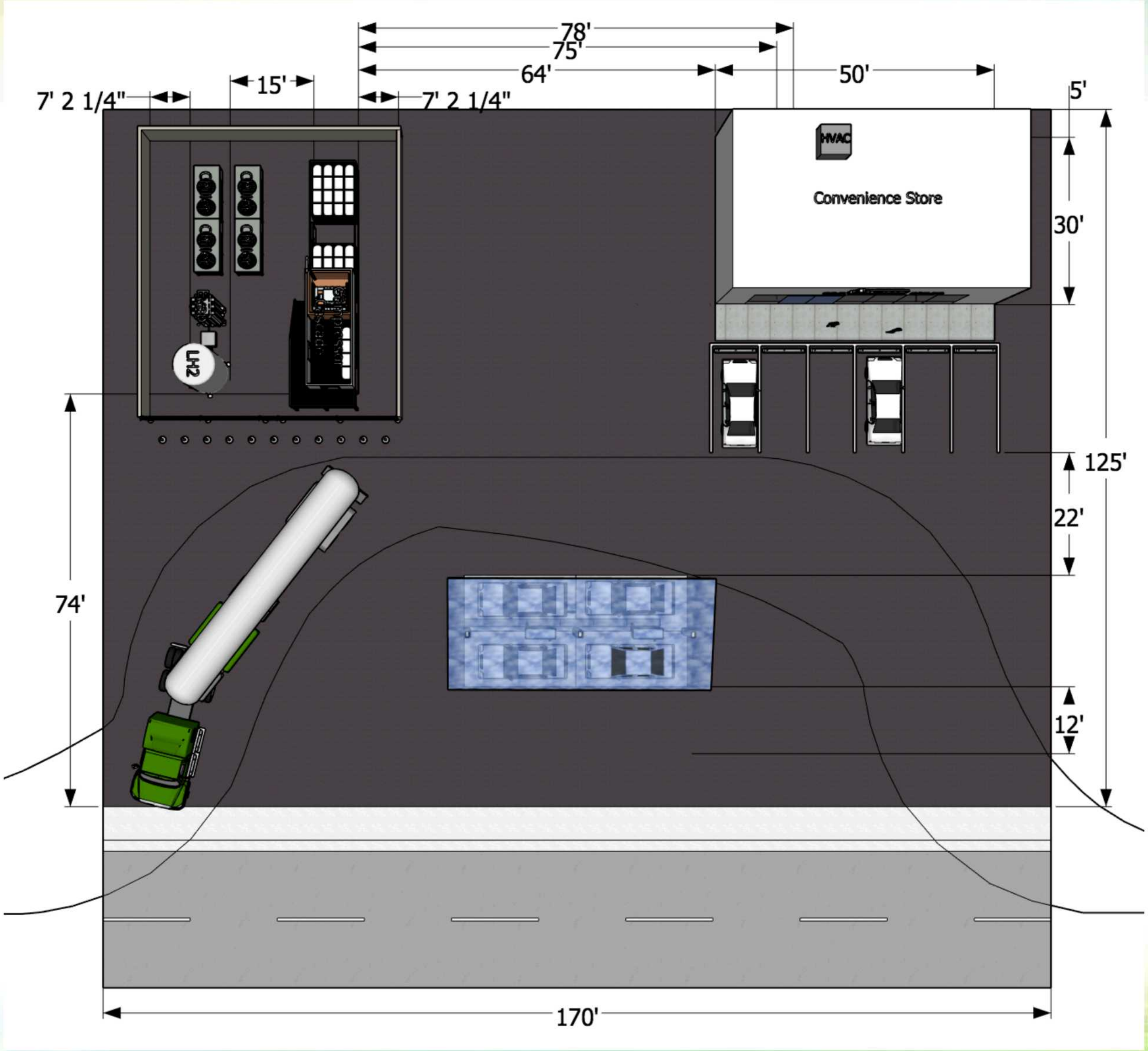


# Base Case Electrolysis: Small footprint without delivery

- PEM electrolyzer (nominal 2 MW)
  - Sized for 24 hour/day use
  - Buffer storage used to smooth flow from electrolyzer to compressor
- 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$^2$



# Base Case Liquid: Large footprint due to delivery truck and non-reducible 75 ft. air intakes setback




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

# Identified challenges in interpretation and implementation of NFPA 2 leading to code updates

## 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
    - 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 55/2***
- Setback distances are different for most exposures, only a few able to be reduced

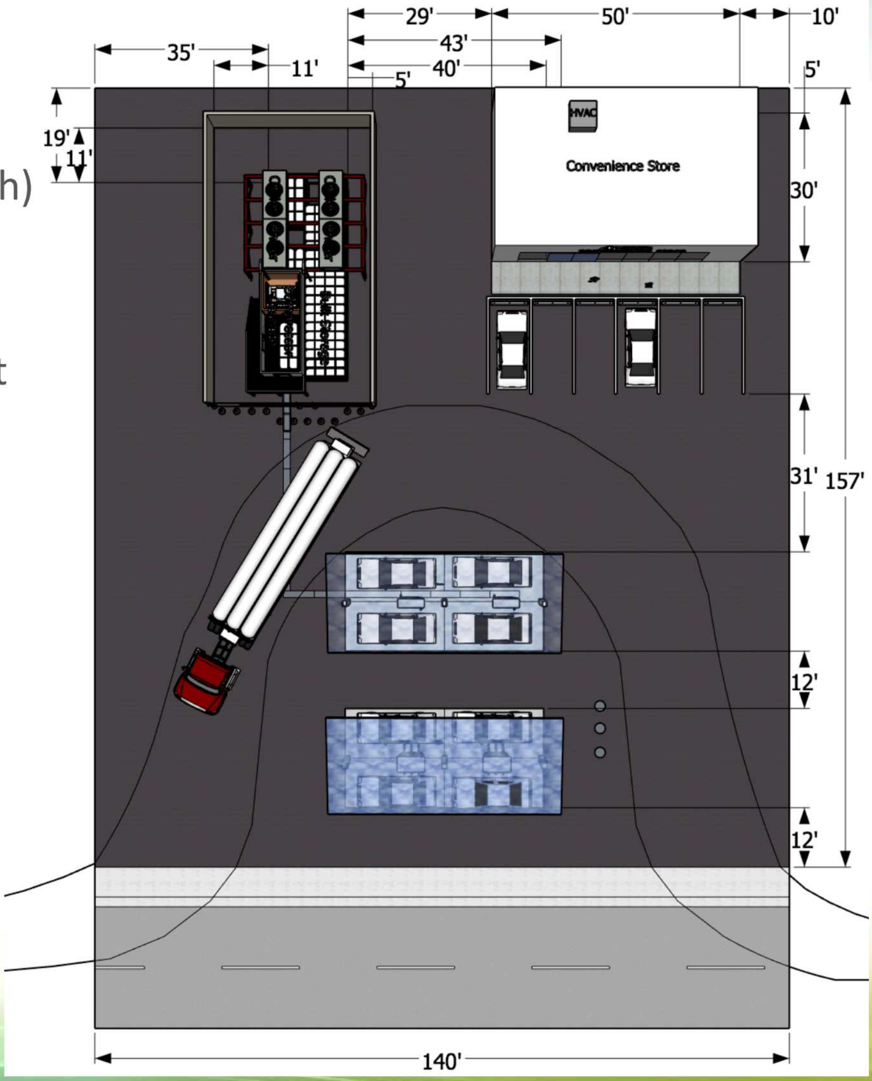
| Group | Exposure | Reducible | Distance |
|---|---|---|---|
| 1 | 1 Lot lines | Yes | 15 m (50 ft) |
| | 2 Air intakes | | 23 m (75 ft) |
| | 3 Operable openings in buildings | | 23 m (75 ft) |
| | 4 Ignition sources | | 15 m (50 ft) |
| 2 | 5 Places of public assembly | | 23 m (75 ft) |
| | 6 Parked 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 H2) | Yes | 23 m (75 ft) |
| | 9 Between stationary LH2 containers | | 1.5 m (5 ft) |
| | 10 All classes of flammable and combustible liquids | Yes | 23 m (75 ft) |
| | 11 Hazardous material storage including LO2 | 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) |

# Developed new designs and compared them to base cases, based on a range of assumptions

- **Effects of 2020 Edition of NFPA 2**
  - Significant impact on minimum footprint
  - But other factors (traffic and delivery truck path) reduce impact on full layout
- **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 additional dispensers

*Different design changes have different impacts on station footprints*

**Gasoline Co-Location**



# Created elevated and underground storage station designs that reduce footprint

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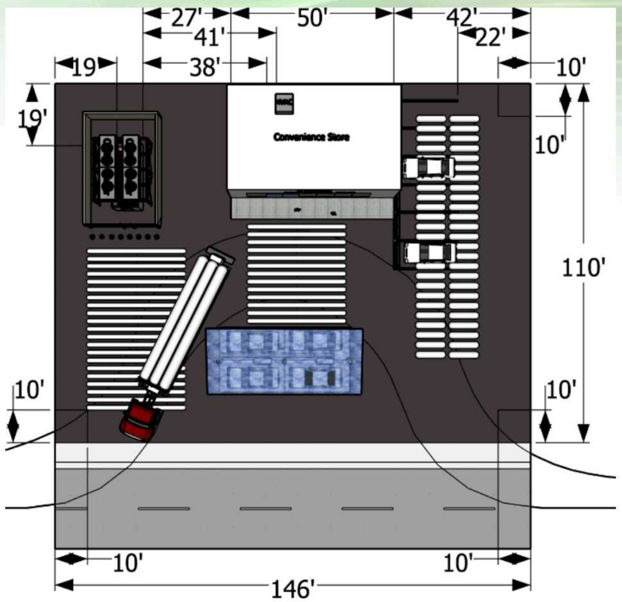
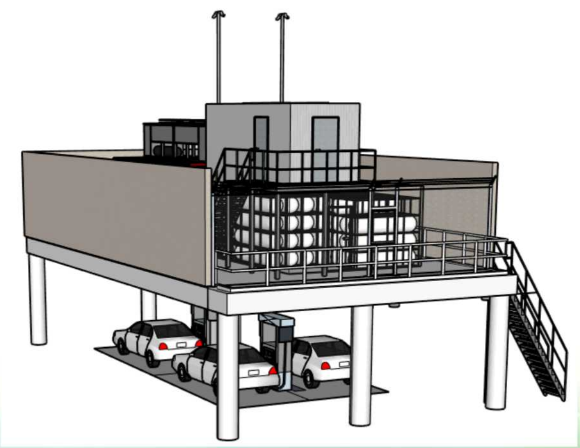


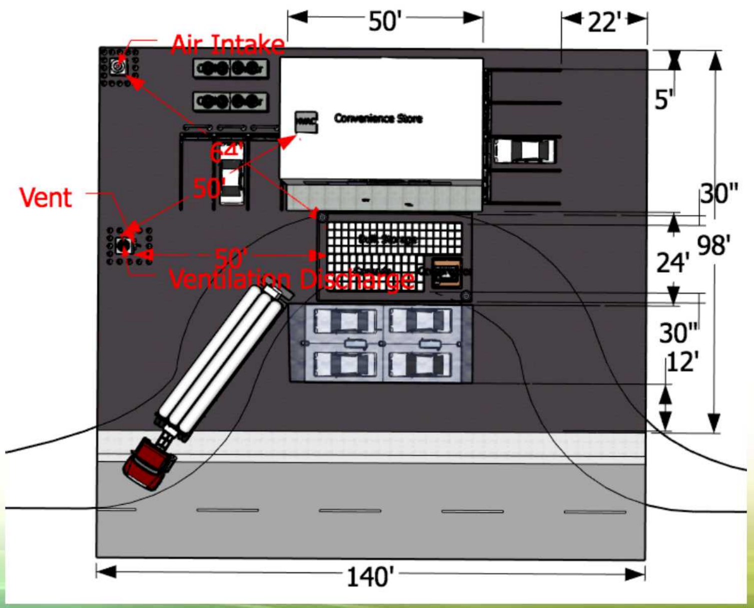

### Underground Storage

- Direct burial
- Vault
- Only buried components eliminate setbacks

### Elevated Storage

- Setback distances still apply to line-of-sight
- Very large weight of equipment
- Seismic loading and aesthetics are issues





# Summary of lot sizes for all cases

| | Design | Total Lot Area ($ft^2$) | Reduction from Base Case |
|---|---|---|---|
| Delivered Gas | 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 | **22.22%** |
| | Rooftop Storage | 15,400 | 12.70% |
| Delivered Liquid | 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 | **26.99%** |
| | Rooftop Storage | 19,840 | 6.63 % |
| On-Site Electrolysis | Base Case | 14,756 | 0.00% |
| | New NFPA Separation Distances | **11,934** | 19.12% |
| | 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% |

# Approximated potential to site stations in dense urban areas

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- 7 cities in 5 states
  - CA, CT, MD, MA, NY
- Total of 227 gasoline stations analyzed
  - Located using Google Maps
- Lot size of each station 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 was identified

*Illustrates potential effect of reduction in lot sizes*

## Siting results on delivered gas designs

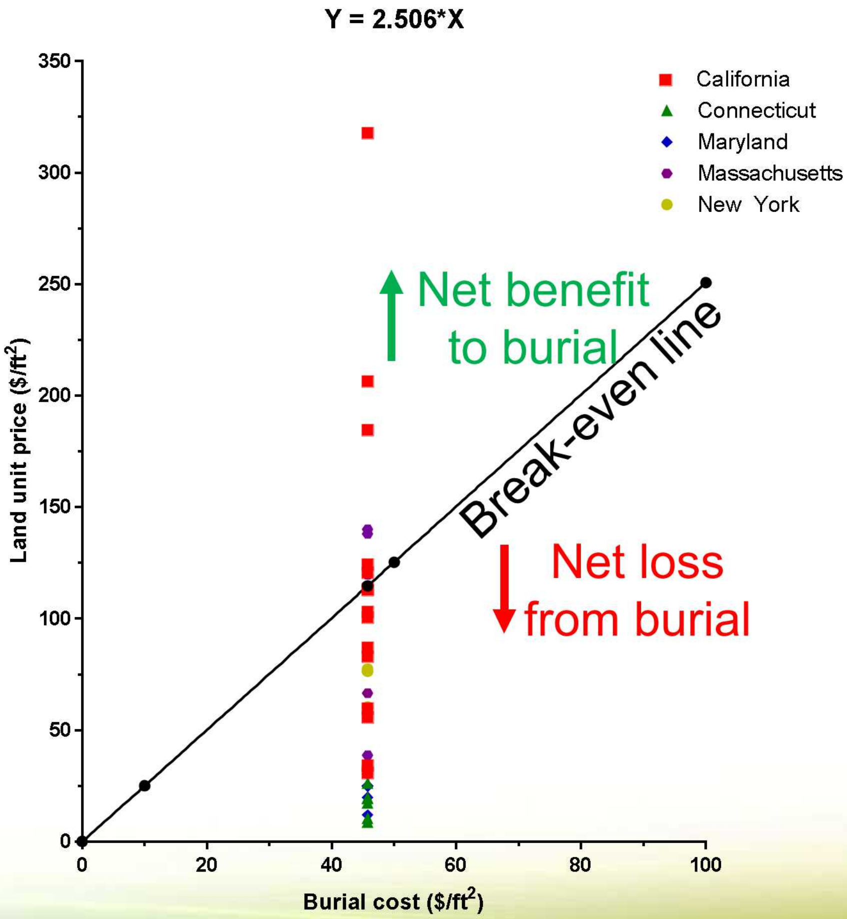
| Design | Lot Area ($ft^2$) | Reduction from Base Case | Lots available (out of 227) [%] |
|---|---|---|---|
| Base Case Gas | 17,640 | -- | 77 [34%] |
| New NFPA Separation Distances | 17,640 | 0.00% | 77 [34%] |
| New Delivery Single Truck | 14,391 | 18.42% | 107 [47%] |
| New Delivery Double Truck | 15,875 | 10.01% | 88 [39%] |
| Gasoline Colocation | 21,980 | -24.60% (increase) | 52 [23%] |
| Underground Direct-Bury | 16,060 | 8.96% | 88 [39%] |
| Underground Vault | 13,720 | 22.22% | 112 [49%] |
| Rooftop Storage | 15,400 | 12.70% | 97 [43%] |

# Demonstrated simplified economic impact of station design changes for underground

- Sub-set of 40 gasoline stations analyzed
- Land unit price ($\$/ft^2$) calculated from county property tax records
- Underground direct-bury cost estimated from underground propane tank installation cost: $\$45.8/ft^2$
- Break-even line determined by ratio of burial area 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

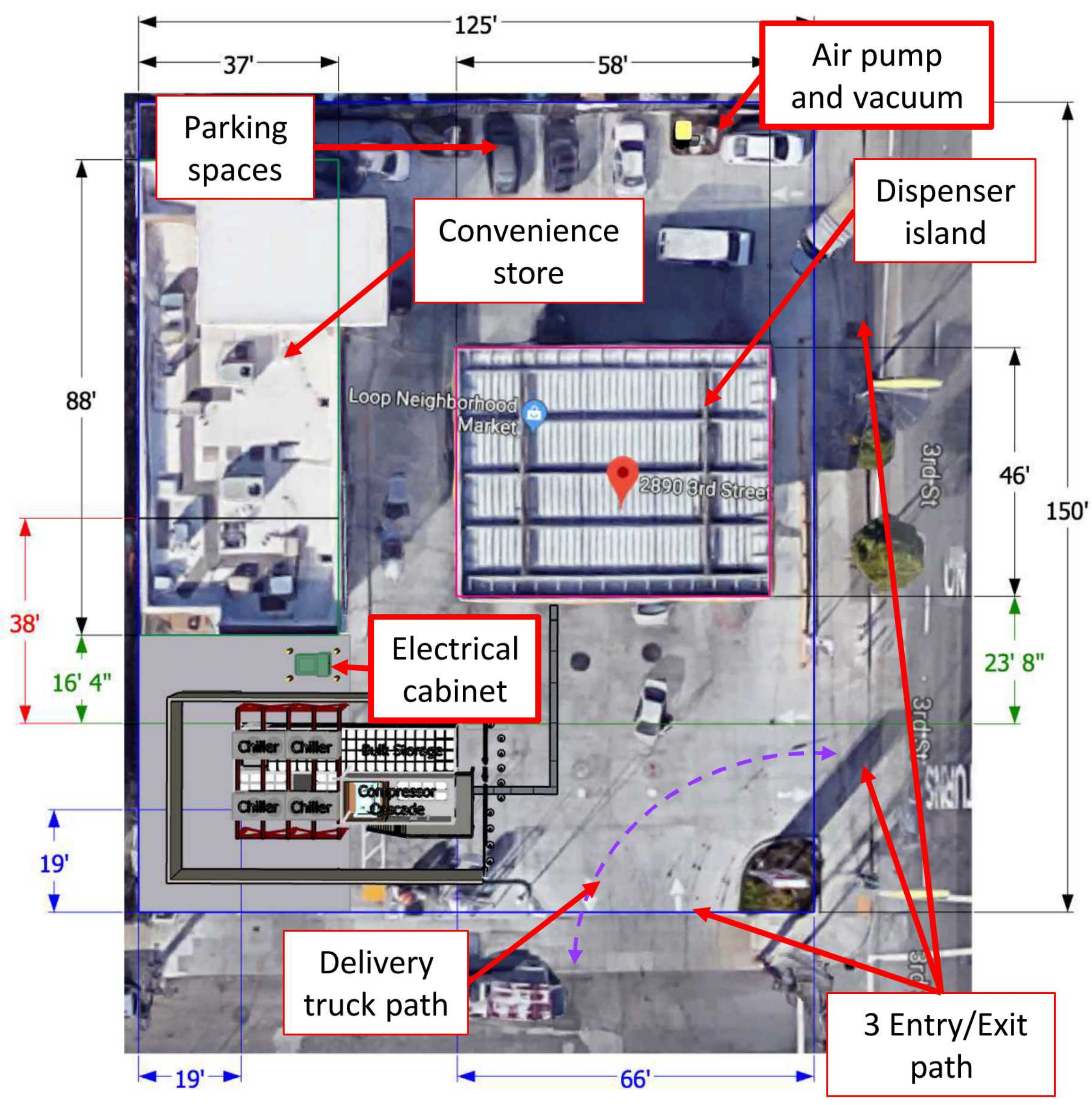


# Performed real station co-location case study to show impact of site-specific features

- 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$^2$ | 21,000 ft$^2$ |
| Convenience store size | 3,256 ft$^2$ | 1,500 ft$^2$ |
| Dispenser island | 2,668 ft$^2$ | 1,600 ft$^2$ |

*Real-world locations will differ from generic designs*



# Summary

- **Relevance and Impact**
  - Reduction of refueling station footprint identified by FCTO and H2USA as high priority
- **Approach**
  - Comparison of different design changes to base cases quantifies impact
  - Changes include NFPA 2 code changes, gasoline co-location, alternate delivery truck, underground storage, and risk-informed designs
- **Accomplishments and Progress**
  - 600 kg/day stations completed for delivered gas, delivered liquid, and on-site electrolysis
  - Footprints quantified for base cases, alternate delivery, upcoming fire code changes, underground and elevated storage, and gasoline co-location
  - Real-world co-location case study on San Francisco gas station
  - Siting study in US cities in California and Northeast shows impact of station lot size changes
  - Economic comparison shows trade-off trends for design changes over wide range of sensitivity
- **Future Work**
  - Final report preparation

# TECHNICAL BACK-UP SLIDES

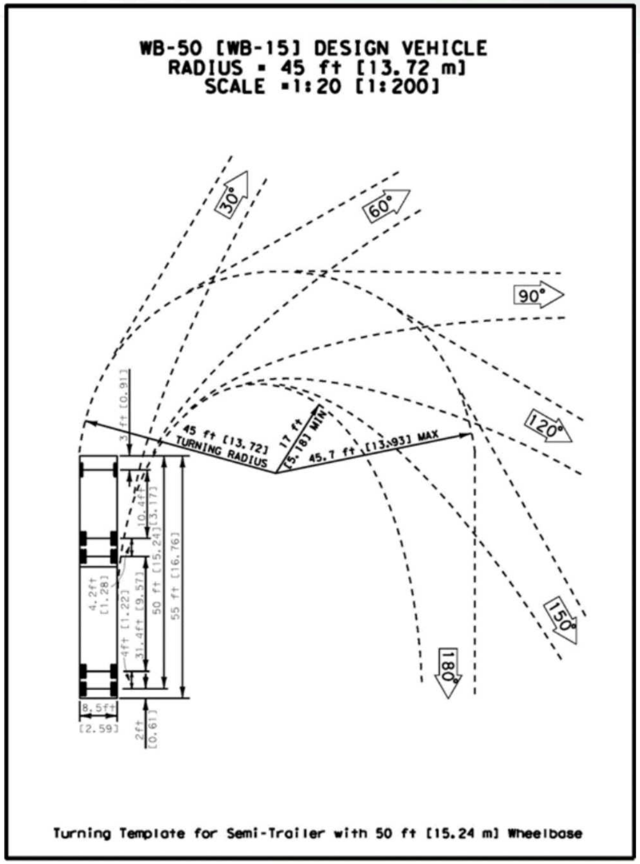
# Collaborations

- 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
  - 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-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

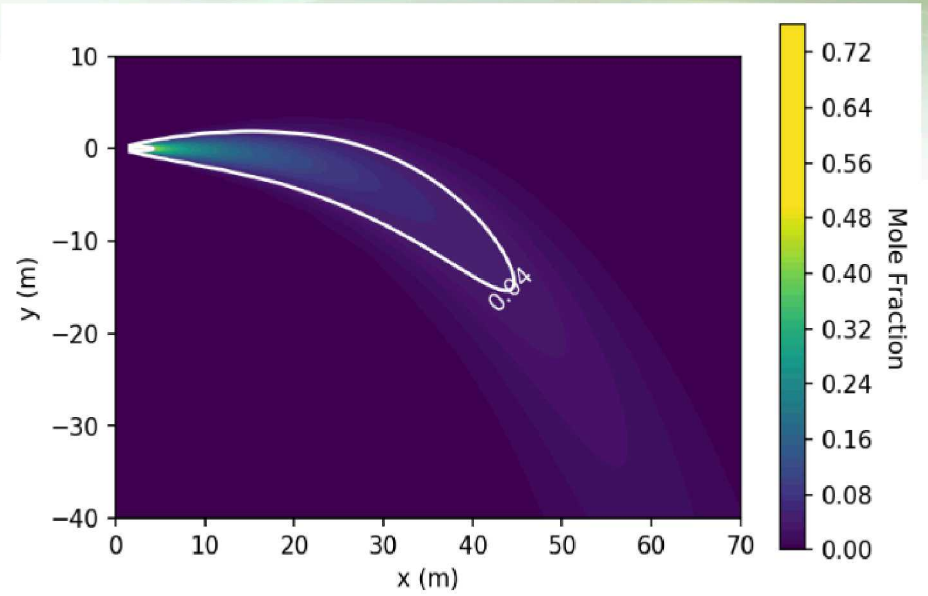


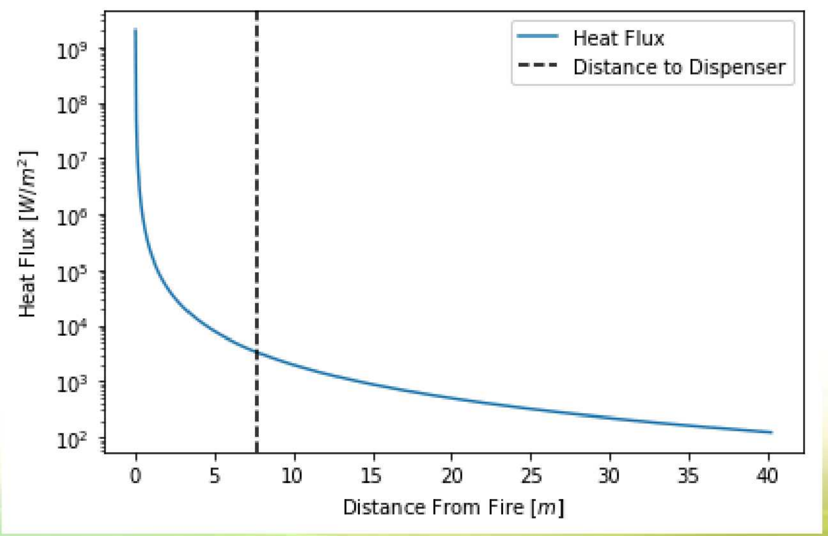

Texas DOT Road Design Manual

# 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 use to determine the separation distances for each exposure
  - Heat flux
  - Hydrogen flammable concentrations
  - Frequency of fatalities

| Exposure | Heat flux | Notes |
|---|---|---|
| Personnel | 1,577 W/m² | Threshold to which personnel with appropriate clothing can be continuously exposed. Used as the **"no harm"** value. |
| Personnel | 4,732 W/m² | Threshold for exposure to employees for a maximum of 3 minutes. |
| Combustible materials | 20,000 W/m² | Minimum heat flux for the nonpiloted ignition of combustible materials, such as wood. |
| Non-combustible materials | 25,237 W/m² | Threshold heat flux imposed by the International Fire Code for noncombustible materials. |

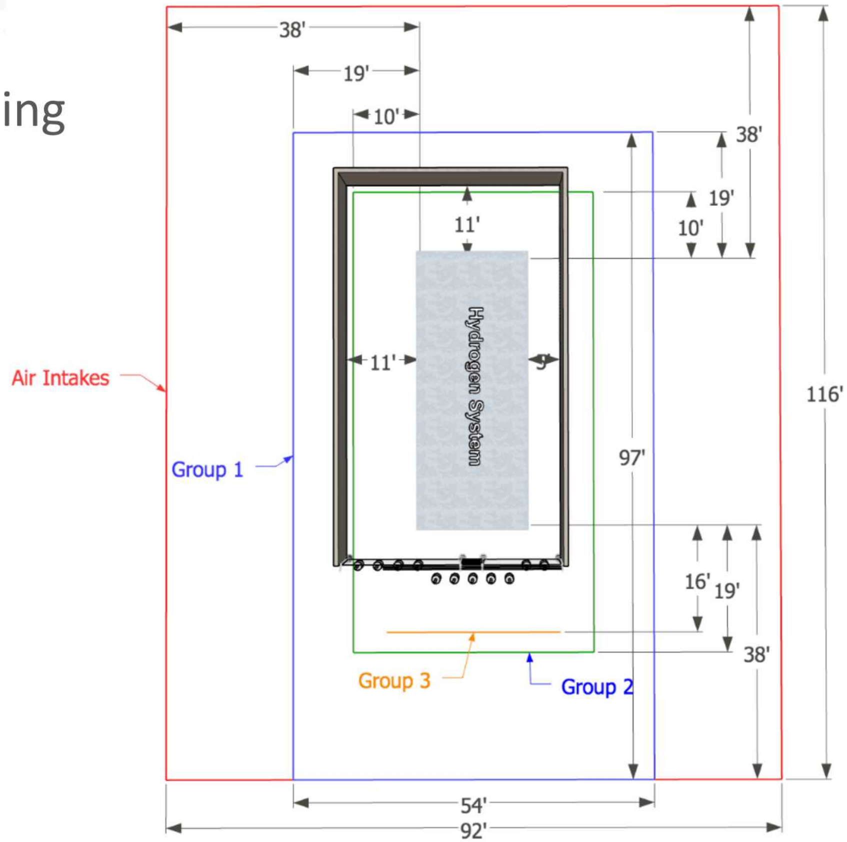


# Accomplishment: Minimum footprint determined from outdoor bulk gas setback distances

- 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*

# Accomplishment: Minimum footprint for outdoor bulk liquid differs significantly from gas

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- 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) |
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# Remaining Barriers and Challenges

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- Project challenge: Station design choices are based on code requirements for general hazards applicable to all stations
  - Choice of basis affects resulting requirements
  - Difference between alternative means and performance-based design
- Industry challenge: Current setback distances only take credit for fire-rated wall
  - Other active or passive prevention or mitigation measures considered only on a case-by-case basis
  - Project challenge: no way to incorporate these credits into generic station designs
- Project challenge: Siting and economics are specific to each particular location
  - Illustrative comparisons are useful for showing trends