Hydrogen Stations for Urban Sites

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Timeline

- Task start date: March 2017
- Task end date: September 2018

Barriers (Delivery)

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

Budget

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

Partners

- NREL

Relevance

- 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

Approach: Footprint and Hazard Comparisons to Base Cases

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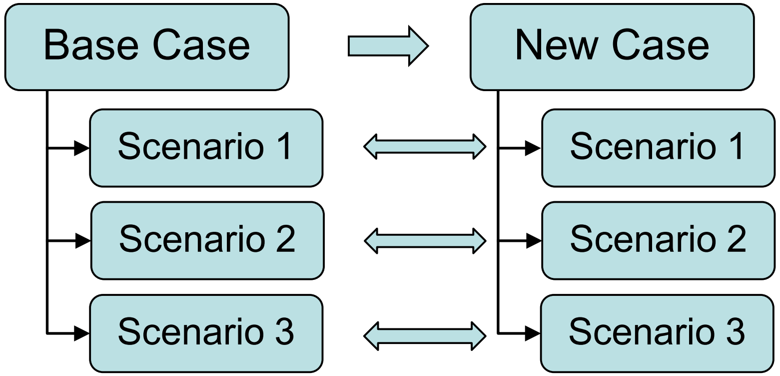
- Previous reference station analyses examined system layout, physical footprint, and cost
  - Current effort focuses on reducing station footprint
- Base case designs for delivered gas, delivered liquid, and on-site production via electrolysis
  - Fully compliant, all requirements and setback distances
  - Design calculations use HRSAM [1]
- Comparisons to base cases:
  - New code requirements
  - New delivery methods
  - Gasoline refueling station co-location
  - Underground storage
  - Roof-top storage
  - Performance-based designs
- Compare risk/consequence for specified hazard scenarios
  - Risk and consequence calculations use HyRAM [2]

Quantification of absolute risk is difficult; comparisons show trends

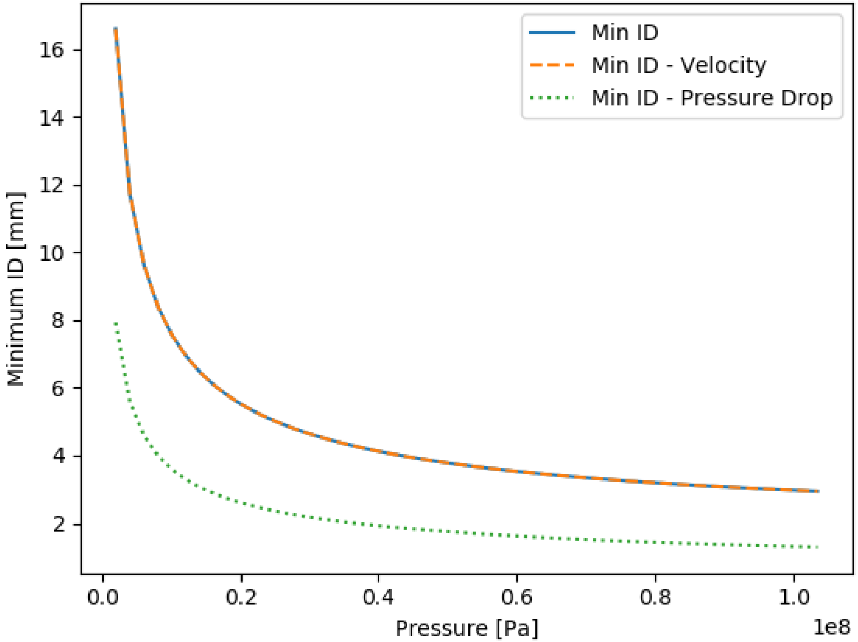


Direct Hazard Comparison

[1] https://hdsam.es.anl.gov/index.php?content=hrsam
[2] http://hyram.sandia.gov/

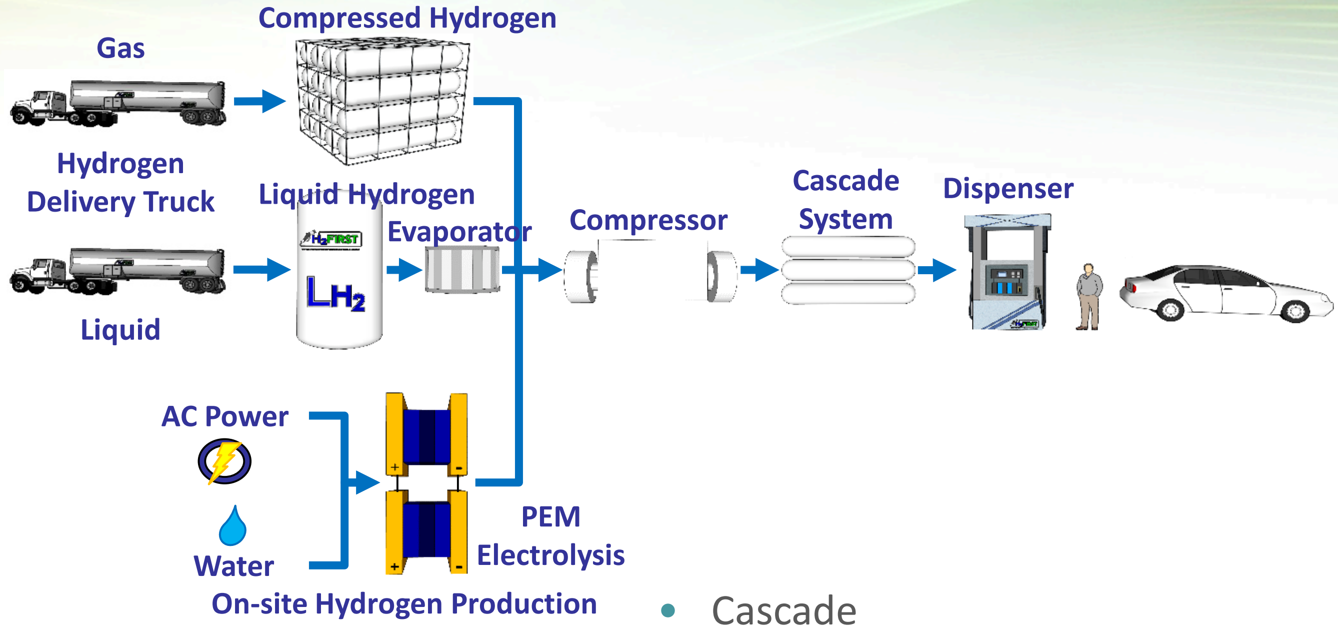
Accomplishments: Station Size and Detail Increased

- Analyzing larger station sizes
  - Previous studies looked at 100, 200, and 300 kg/day dispensed H_2 with 1 or 2 hoses
  - This work considers only 600 kg/day dispensed H_2 with 4 dispenser hoses on 2 dispensers
- Level of detail increased for station design elements that affect code requirements
  - Flow pressure drop and velocity design rules used to size tubing
  - Setback distances required by NFPA 2 based on both tube pressure and size



Larger and more detailed system description reveals previously unexplored code requirements

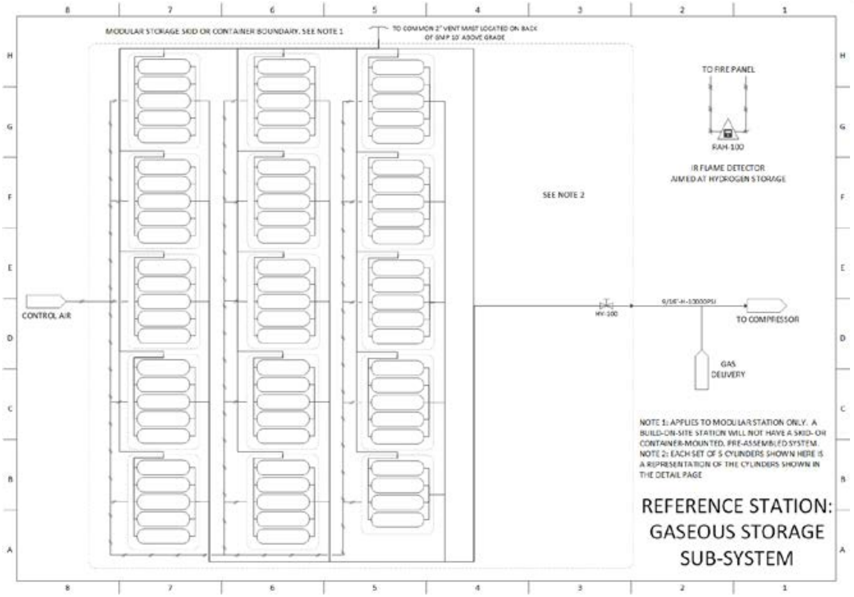
Accomplishments: Specified Similar Component Needs for Three Hydrogen Sources



- Compressor
  - 25 kg/hr flow rate (constant 600 kg/day)
  - Outlet pressure of 94.4 MPa (13,688 psi)
  - 75% isentropic efficiency, 91% motor efficiency, and a 110% motor over-design
- 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 40 kg/hr to each dispenser
  - Low pressure 31.0 MPa (4,500 psi) yields minimum ID of 5.78 mm (0.23”)
    - Example tubing 14.3 mm (0.5625”), ID of 6.4 mm (0.25”)
- Dispensing
  - 4 fueling positions, 70 MPa, -40°C

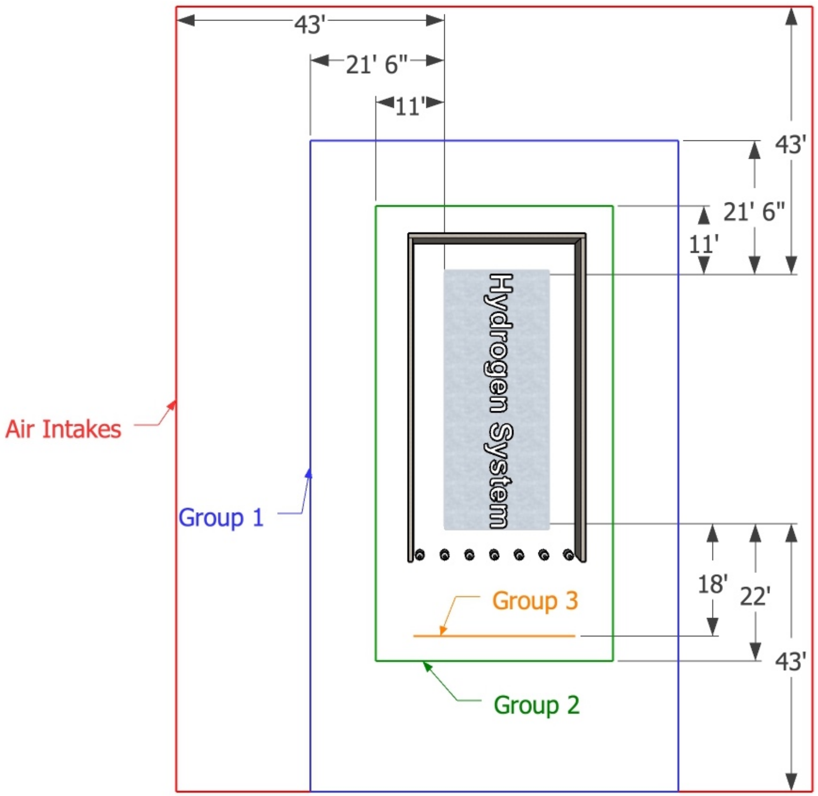
Accomplishments: Detailed Design for Delivered Gas Base Case

- Bulk Gas Storage
  - Sized for 33% over daily design capacity
  - Max pressure of 50 MPa (7,250 psi)
  - 800 kg H_2 yields 25.2 m^3 total hydraulic volume
  - Multiple cylinders in ISO-sized superstructure
  - Connecting tubing 25 kg/hr at minimum pressure 6.9 MPa (1,000 psi) yields minimum ID 9.1 mm
    - Example tubing OD 14.3 mm (0.5625"), ID 9.11 mm (0.359"), pressure rating 103.4 MPa (15,000 psi)



Accomplishments: Minimum Footprint/Full Layouts for Base Case Delivered Gas

- Minimum Footprint
  - Hydrogen station only



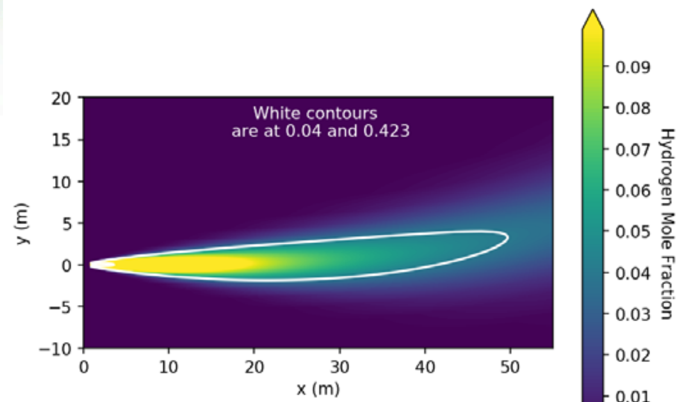
- Full Layout
  - Convenience store
  - Parking
  - Traffic flow
  - Delivery

Non-hydrogen station components have large effect on final station layout

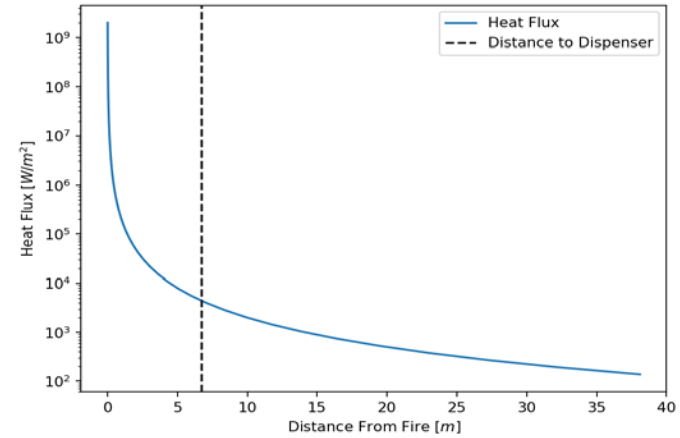
Accomplishments: Hazard Scenario Analysis

NFPA 2 Required Scenario	Fueling Station Scenario	Base Case Gas Result
Fire	H_2 fire resulting from a leak at the H_2 dispenser	AIR = 2.241 × 10^{-6} fatalities/year
Pressure Vessel Burst	Compressed gas storage	Mitigations listed for stationary pressure vessels
Deflagration	A H_2 deflagration within compressor enclosure	3.89 × 10^5 Pa overpressure for 1% pipe size leak
Detonation	Localized H_2/air mixture in vent pipe	Vent pipe L:D ratio is present
Unauthorized Release	Release of H_2 from storage vessel	Hypoxia met within 4 m of the release point
Exposure Fire	Unrelated vehicle fire at the lot line	Heat flux on dispenser: 4.4 kW/m^2
External Event	Seismic event where largest pipe bursts	AIR = 2.151 × 10^{-2} fatalities per year, conditional on earthquake
Protection System Out of Service	H_2 discharge where the interlock fails	No additional risk scenarios because interlocks not credited above
Emergency Exit Blocked	H_2 system outdoors	Not applicable
Fire Suppression Out of Service	H_2 system outdoors	Not applicable

Hazard analysis results for base cases will be compared to other cases

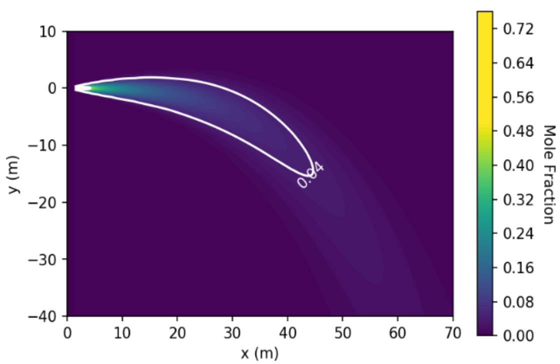


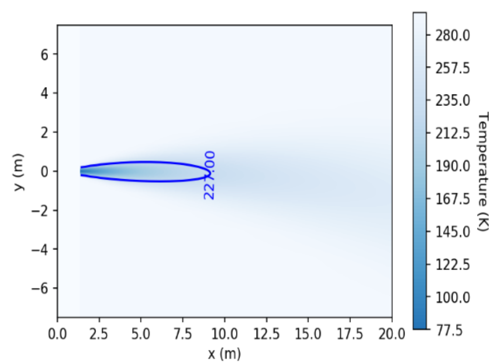
HyRAM
HYDROGEN RISK ASSESSMENT MODELS

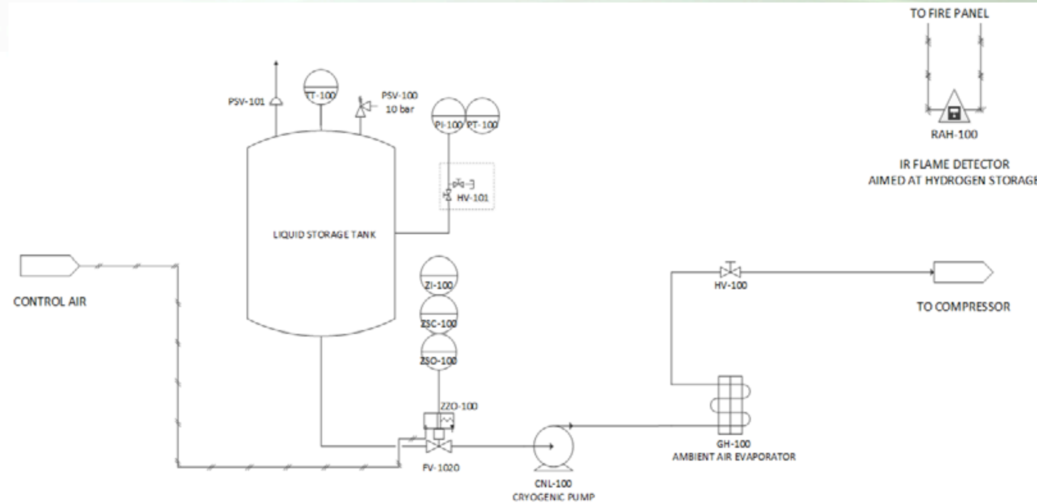


Accomplishments: Detailed Design and Hazard Analysis for Delivered Liquid Base Case

- Bulk liquid storage
  - Sized for 33% over daily design capacity
  - 800 kg, 11,299 L (2,985 gal)







- Hazard analysis: two scenarios different than base case gas
  - Hazardous Material Scenario 1 - Release of hydrogen from storage tank
    - Hypoxia and temperature criteria met within 5 m and 10 m of release, respectively
  - Hazardous Material Scenario 3 - Seismic event where a pipe bursts
    - AIR = 8.789 × 10^{-3} fatalities/year, conditional on earthquake

Hazard analysis results for base case will be compared to other cases

Accomplishments: Detailed Design and Hazard Analysis for On-Site Electrolysis Base Case

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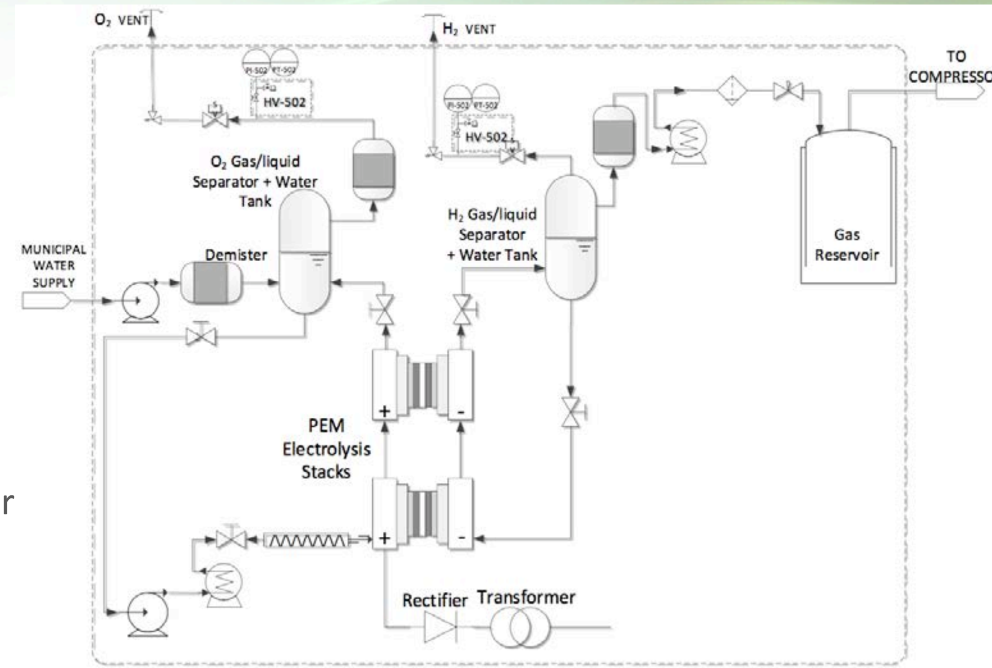
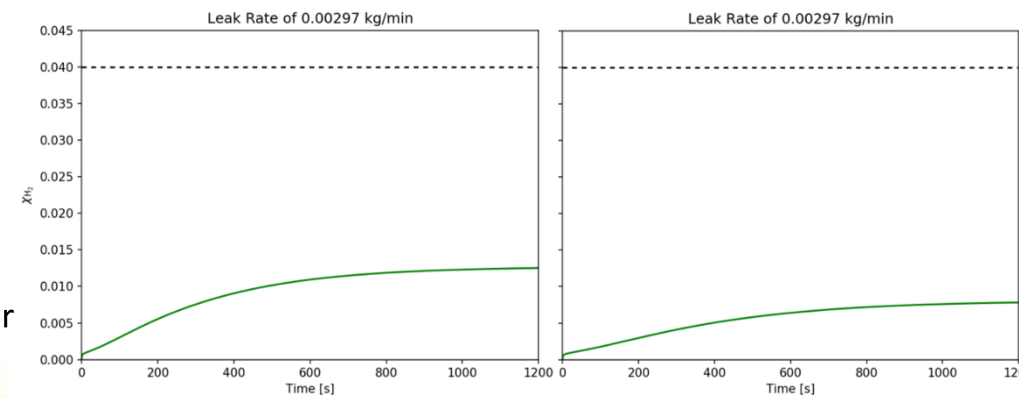
- PEM electrolyzer to meet demand
  - H_2 production up to 36 kg/hr
  - Nominal input power ~2MW
  - Tap water consumption <16 liters/kg-H^2
  - Approximate footprint 40 ft + 20ft container
- GH_2 low pressure storage (gas reservoir)
  - Total capacity of 25 kg at 50 bar
  - Supplies 15 kg of GH_2 at 20 bar to compressor
- Hazard analysis: only some scenarios different than gas
  - Explosion Scenario 2 – Deflagration
    - Compressor enclosure
    - Electrolyzer enclosure
  - Hazardous Material Scenario 3 - External Event
    - Seismic event where largest pipe bursts
    - Largest pipe is in the electrolyzer container





20-feet iso-container

40-feet iso-container

Progress: Code Issues Identified

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- Gaseous setback distances
  - Large system can have bulk storage before and after compressor
  - Multiple approaches possible:
    - 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

	Table 7.3.2.3.1.1	Max. Pressure	Max. ID	Group 1	Group 2	Group 3
Bulk Storage	(a)	50.0 MPa (7,250 psi)	N/A	9 m (29 ft)	4 m (13 ft)	4 m (12 ft)
	(b)		9.07 mm (0.357")	10 m (33 ft)	5 m (16 ft)	4 m (14 ft)
Cascade	(a)	94.4 MPa (13,688 psi)	N/A	10 m (34 ft)	5 m (16 ft)	4 m (14 ft)
	(c)		6.4 mm (0.25")	9 m (30 ft)	4 m (14 ft)	4 m (13 ft)
Single System	(a)	94.4 MPa (13,688 psi)	N/A	10 m (34 ft)	5 m (16 ft)	4 m (14 ft)
	(c)		9.07 mm (0.357")	13 m (43 ft)	7 m (22 ft)	5 m (18 ft)

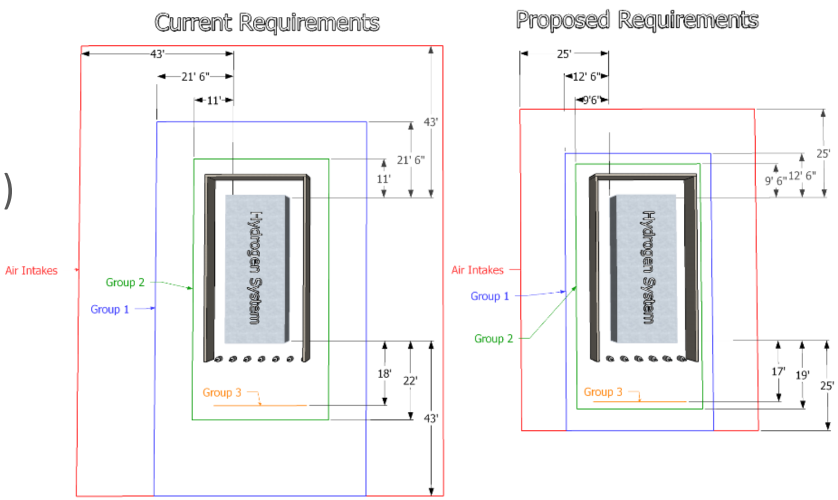
Calculations for larger system may lead to unintended setback distances

- Liquid setback distances
  - Hybrid system (liquid-to-gas) counted as all-liquid system
    - 800 kg LH2, 620 kg GH2
    - 1,420 kg H2 total, increases setbacks
  - 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)

Progress: Effects of Future Changes to NFPA 2

- Next edition of NFPA 2 code under review
- Setback distances reduced for bulk gaseous storage
  - For example, for pressure of 94.4 MPa (13,688 psi) and ID of 9.07 mm (0.357”)

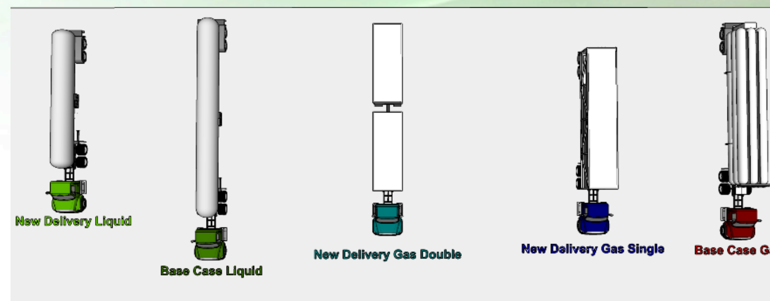


	Group 1	Group 2	Group 3
Current	13 m (43 ft)	7 m (22 ft)	5 m (18 ft)
Proposed	8 m (25 ft)	6 m (19 ft)	5 m (17 ft)

  - Significant impact on minimum footprint, but other factors (traffic and delivery truck path) will likely reduce impact on full layout
- For bulk liquid storage, some setback distance clarifications
  - Fire-rated walls can reduce walls to 0 m, amount of reduction currently unspecified
  - Group 1 and 2 exposures reduced by specific mitigations for delivery unloading connections
  - Likely not a large impact on footprint, but alternate designs with different delivery methods possible

Current NFPA 2 proposals are subject to change, but could have a large impact on station layout

Progress: Different Delivery Methods Considered



- Delivery truck specifications can have a large impact on station utilization and layout
  - Low delivery capacity or pressure mean station utilization is limited
  - Truck dimensions and turning radius can have a significant impact on station layout
- Delivery truck specifics will depend on local market conditions and supplier availability

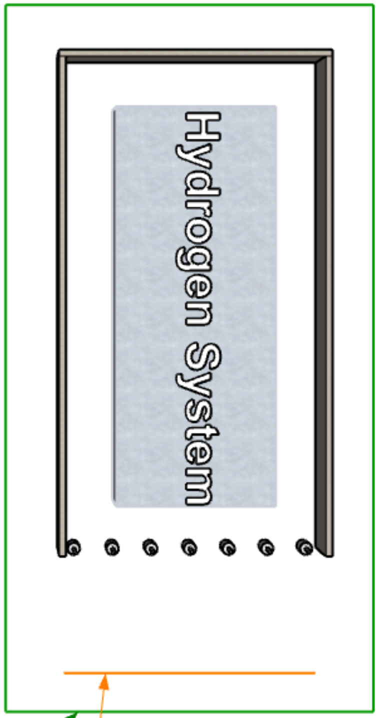
	Delivered Gas		**Delivered Liquid**	
	Base Case	New Delivery	Base Case	New Delivery
Hydrogen Pressure	25 MPa (3626 psi)	50 MPa (7,252 psi)	--	
Hydrogen Capacity	300 kg	1,200 kg	3,000 kg	1,800 kg
Truck-Trailer Length	16.76 m (55 ft)	13.72 m (45 ft)	19.8 m (65 ft)	13.7 m (45 ft)

- Delivered Gas
  - Base assumptions under-utilize station
  - "New" option can fully utilize station
  - Shorter delivery truck will lead to smaller footprint
- Delivered Liquid
  - Both Base Case and "New" can fully supply multiple stations
  - Shorter delivery truck will lead to smaller footprint

Delivery very localized, but can still have major impact on station design

Progress: Analyzing Gasoline Fueling Station Co-Location

- A code compliant co-location station needs to satisfy the following regulations:
  - NFPA 2 and NFPA55
    - GH2 is classified as a flammable gas
    - LH2 is classified as a flammable cryogenic fluid
  - NFPA 30 and 30A
    - Gasoline is classified as a Class IB flammable liquid
- Setback distances for bulk GH_2 and bulk LH_2 systems
  - Group 2 exposures: limits the setback distances to the gasoline dispensers
  - Group 3 (d for GH_2 and 10 for LH_2) exposure: limits the setback distances to the gasoline underground storage tanks (or fill openings).
- Setback distances for Gasoline system (underground storage)
  - Underground storage tanks need to be at least 3 ft from property lines
  - Filling, emptying, and vapor recovery connections should be at least 5 ft from building opening or air intakes



Group 2 and 3 exposures distances can be used to determine layout for co-location station.

Response to Reviewer Comments

- This is a new project, and was not reviewed last year

Collaborations

H2FIRST

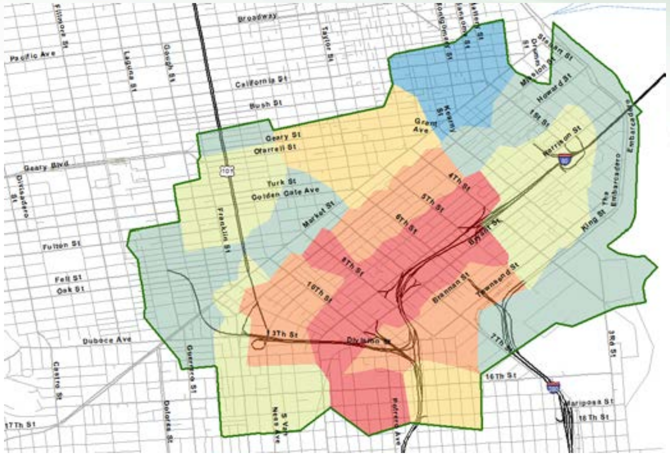
- H2FIRST itself is a **SNL-NREL** co-led, collaborative project and members of both labs contributed heavily to this project.
- To be as relevant and useful as possible, the project tightly integrated input, learnings, and feedback from many stakeholders, such as:
  - H2USA's Hydrogen Fueling Station 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
  - First Element

Remaining barriers and challenges:

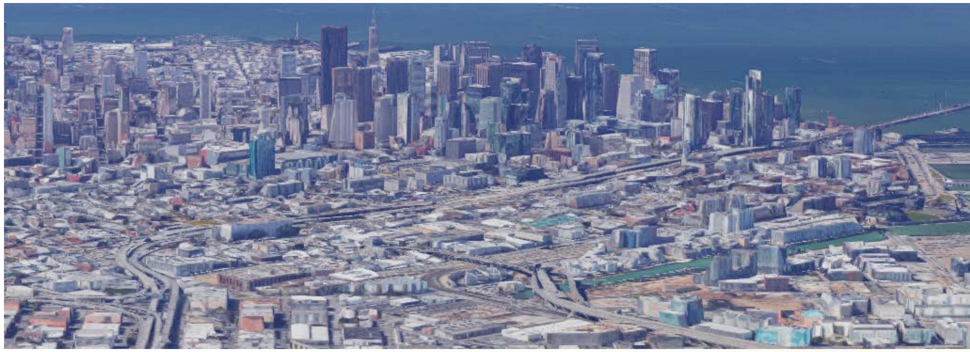
- General footprint difficult to apply to nationwide siting study
  - Site-specific considerations difficult to account for
- Code requirements difficult to interpret
  - Could lead to different interpretations by different AHJs
  - More pronounced differences in interpretation for performance-based designs
- Underground and aboveground storage much more site-specific
  - Underground utilities or structures could prevent burial of storage
  - Jurisdiction-specific height restrictions could limit roof-top storage

Future work:

- Underground and roof-top storage analysis
  - Quantify footprint reduction
  - Identify other possible methods for further reduction
- Performance-based designs
  - Smaller than NFPA 2 setbacks, but equivalent or lesser risk
  - Typically site-specific, but can identify general trends
  - Could help inform future code changes
- Economic evaluation
  - Based on previous reference stations
  - Will consider economic impact of different footprint reductions
- National siting study for reduced footprint
  - Can quantify effect of varying footprint size
- Host workshop with stakeholders to present results and outline future needs



Preferred location of stations in San Francisco



Any proposed future work is subject to change based on funding levels

Summary

H2FIRST

- **Relevance**:
  - Create compact 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
- **Approach**:
  - Direct comparison of hazards/risks for base cases vs. alternative layouts with reduced footprints
- **Accomplishments and Progress:**
  - Completed base case designs and hazard analysis for delivered gas, delivered liquid, and on-site electrolysis
  - Identified upcoming code changes, alternate delivery assumptions, gasoline co-location
- **Future Work**:
  - Underground and roof-top storage analysis
  - Performance-based designs
  - Economic evaluation
  - Siting study for reduced footprint
  - Host workshop

TECHNICAL BACK-UP SLIDES

Compressor, Cascade, and Dispenser P&IDs