Lab-scale dispersion of cryogenic hydrogen jets

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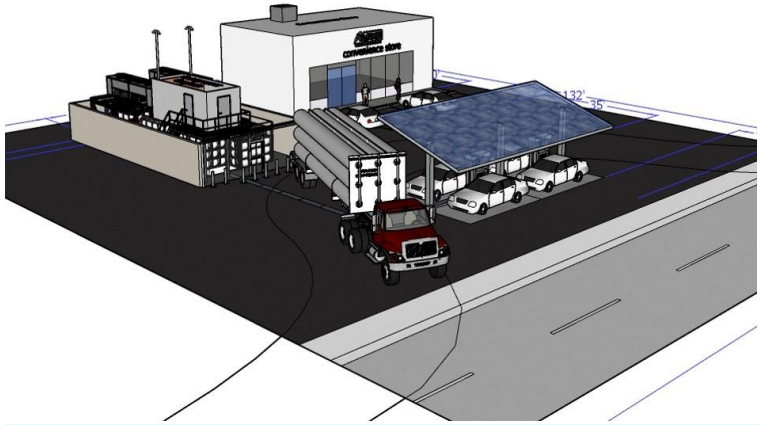
SAND2021-5510 C

The objective of our work is to provide a scientific basis for exposure distances in the U.S. fire code, NFPA 2

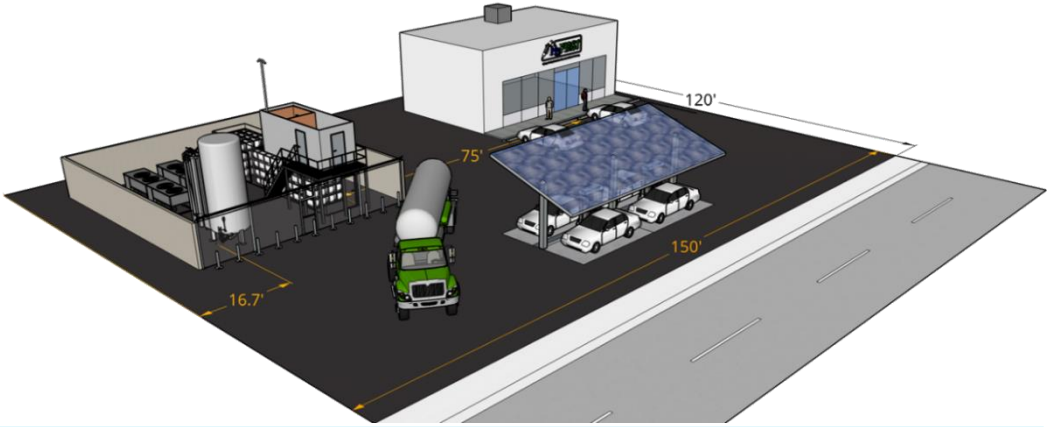
Compressed H_2 storage

- Previous work by Sandia led to science-based gaseous H_2 separation distances



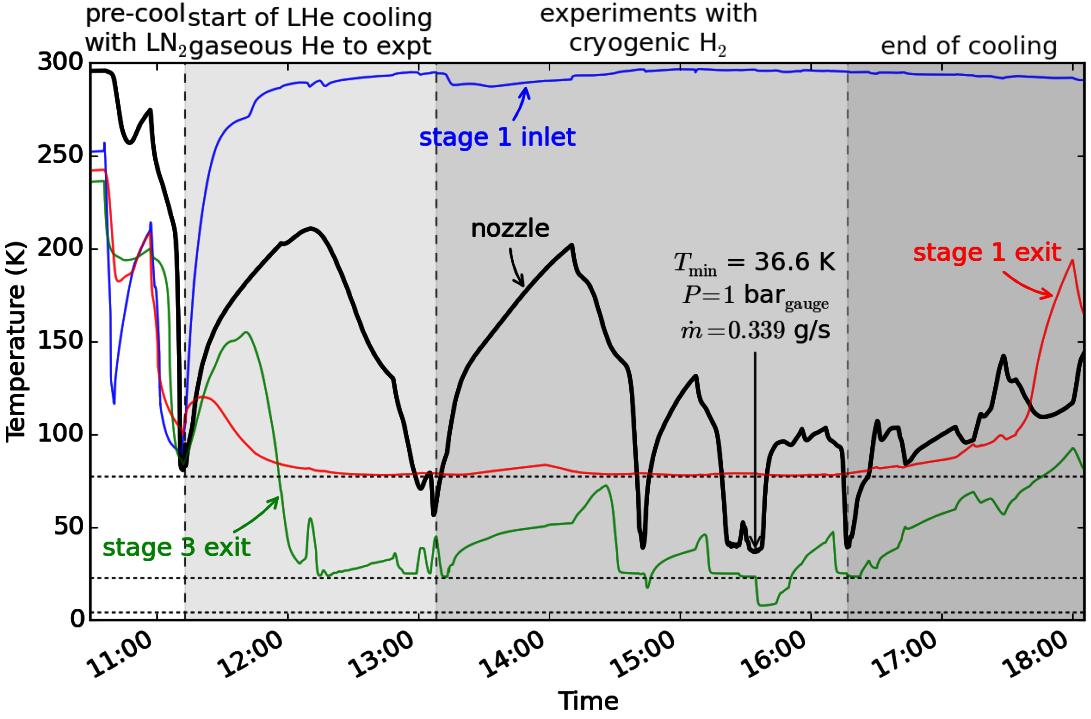
Liquid H_2 storage

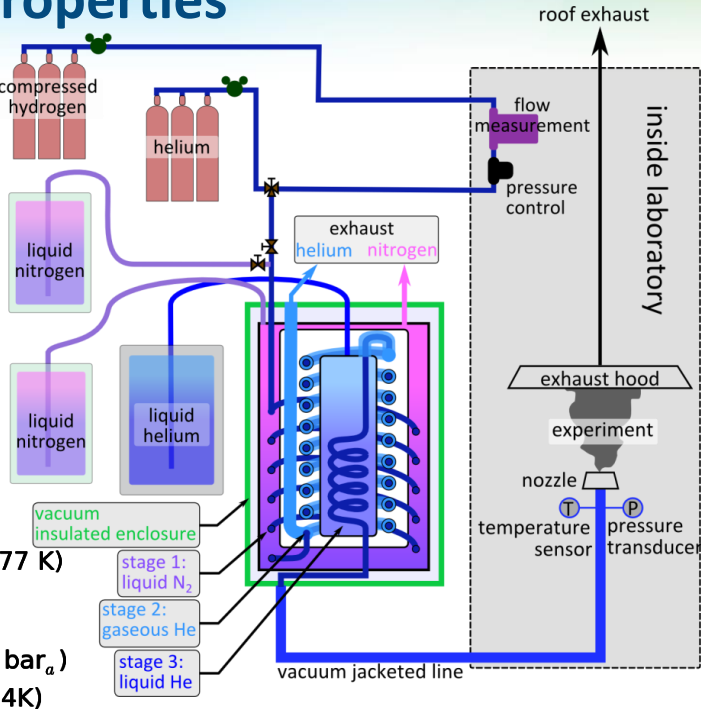
- Even with credits for insulation and fire-rated barrier wall, 75 ft. offset to building intakes and parking make footprint large



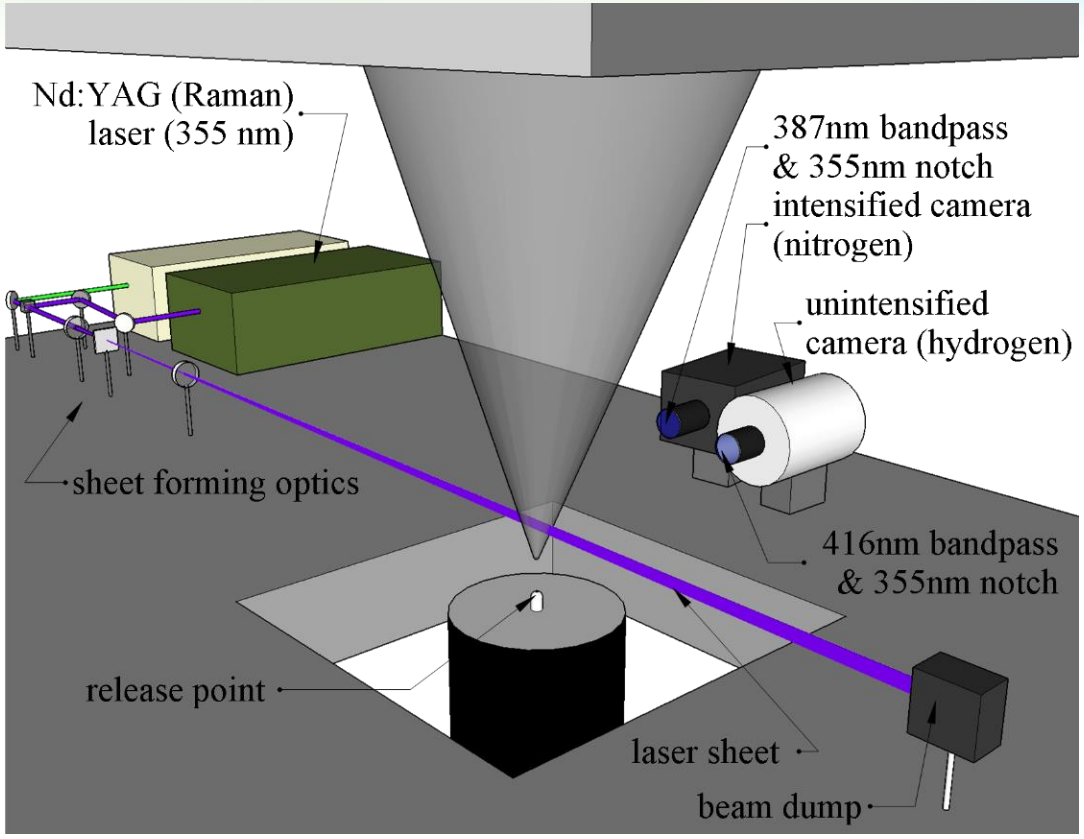
DOE goal: By September 30, 2022, identify ways to reduce the siting burdens that prohibit expansion of hydrogen fueling stations, through hydrogen research and development that enables a 40% reduction in station footprint, compared to the 2016 baseline of 18,000 square feet

We have performed experiments releasing cryogenic hydrogen in the laboratory to study its dispersion and flame properties





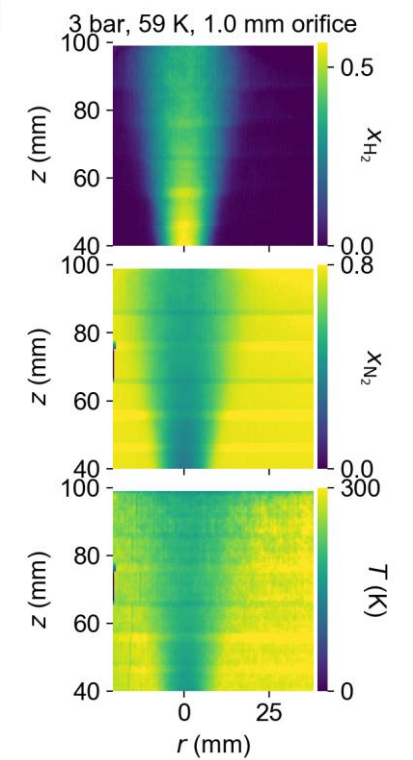
H_2-N_2 Raman imaging has been used to measure concentration and temperature of cryogenic H_2

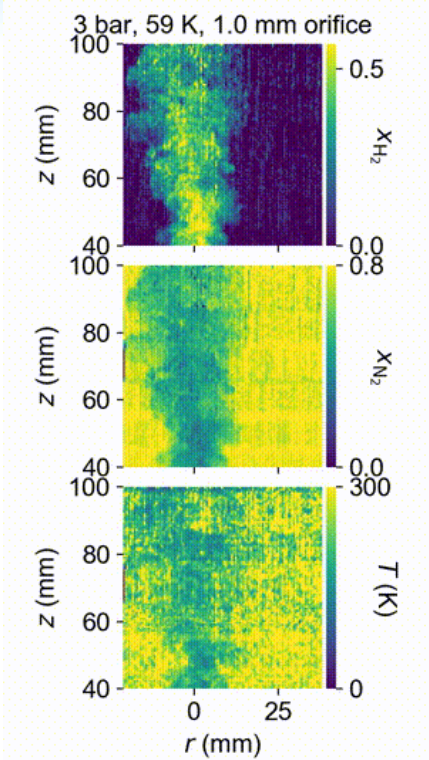


- Rayleigh used for room temperature releases, but signal overwhelmed by Mie scattering off of condensed water vapor in cryogenic jet
- Filtered Rayleigh had insufficient Mie scattering light suppression (OD≈3)
- Raman scattering enables higher optical density filters
- Enables simultaneous measurement of concentration and temperature in 2D

An experimental campaign with round nozzles had variations in temperature, pressure, and nozzle size

T_{noz} [K]	P_{noz} [bar_{abs}]	d [mm]	T_{throat} [K]	n_{hts}
58	2	1	43.5	4
56	3	1	41.9	4
53	4	1	39.6	4
50	5	1	37.4	5
61	2	1.25	45.7	6
51	2.5	1.25	38.2	2
51	3	1.25	38.2	6
55	3.5	1.25	41.2	3
54	4	1.25	40.4	2

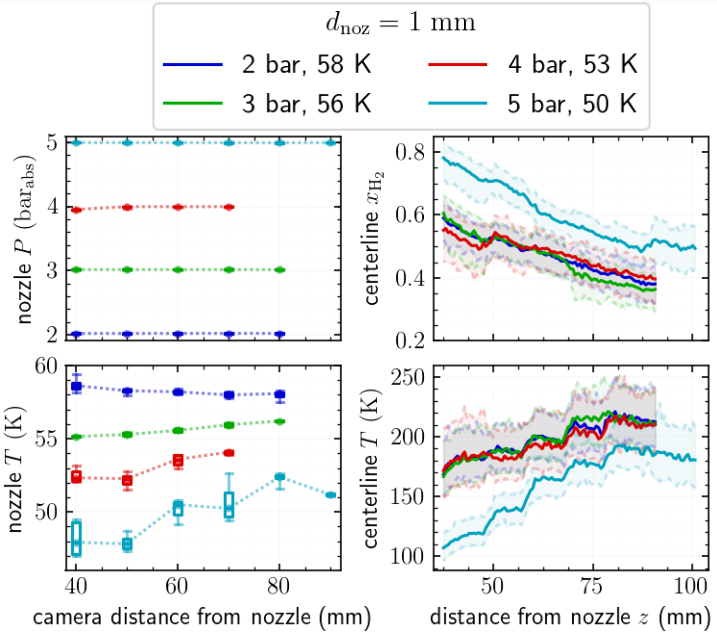


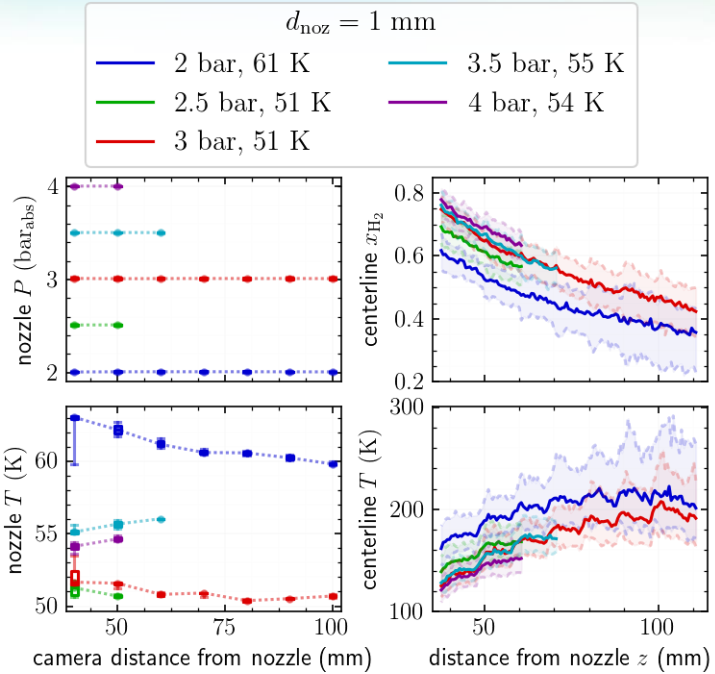


Independent model parameters:

- ✓ T - temperature
- ✓ x - mole fraction
- ✓ v - velocity
- ✓ B - halfwidth (both velocity and concentration)

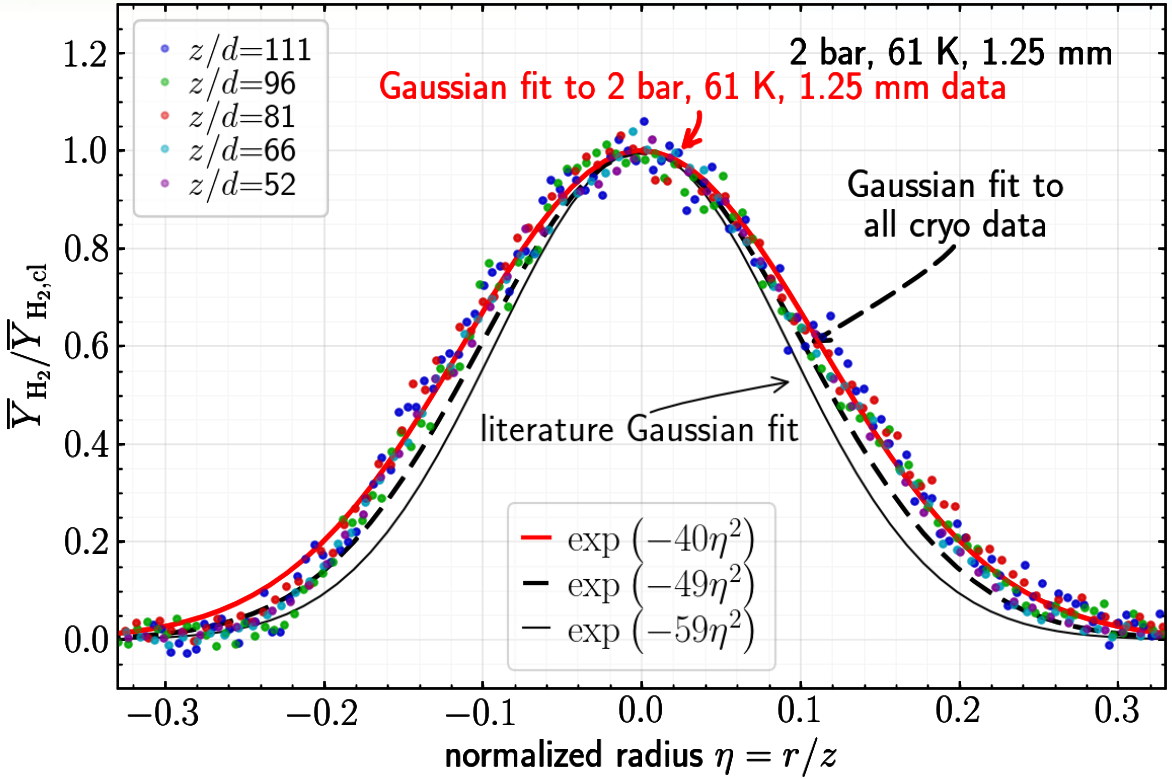
Pressure at the nozzle was controlled; temperature was measured during experiments



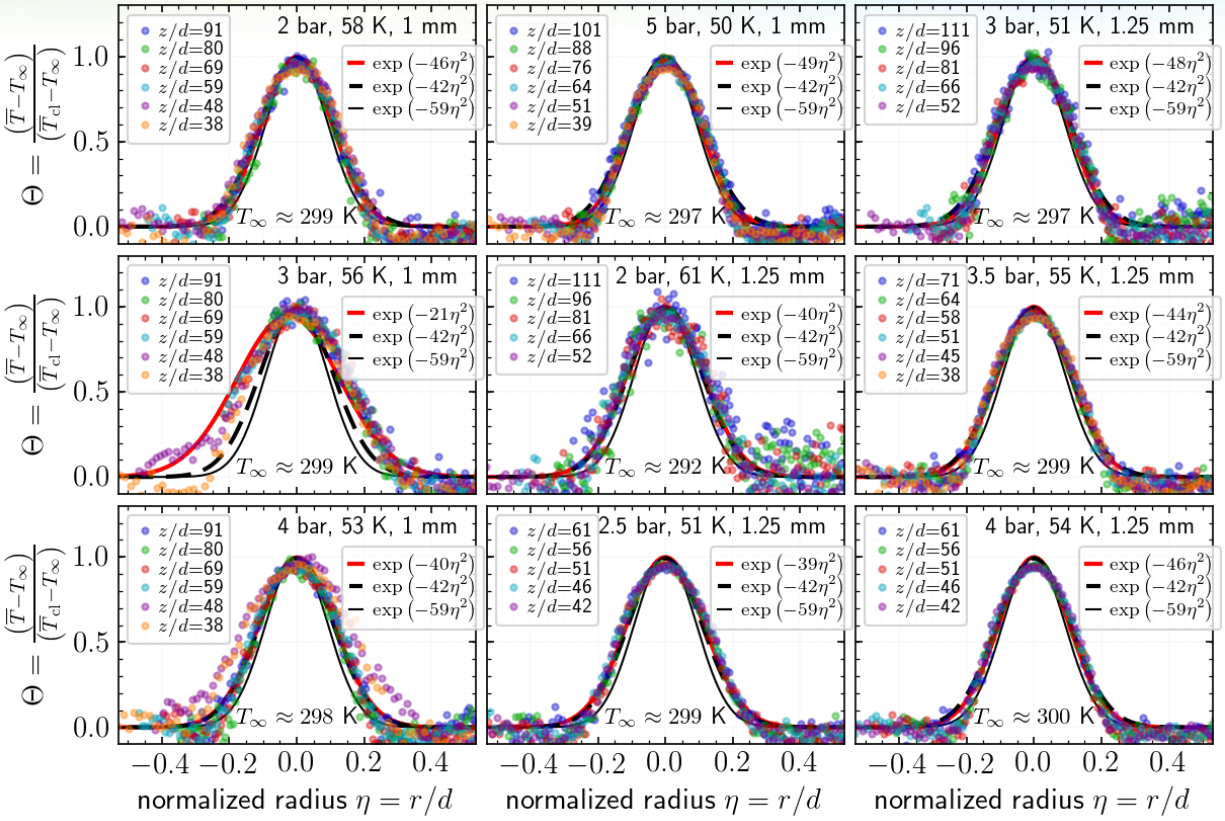


➢ Centerline mole fractions decrease and temperatures increase, as expected

The 2-dimensional profiles are self-similar, and slightly wider than literature data of warm releases

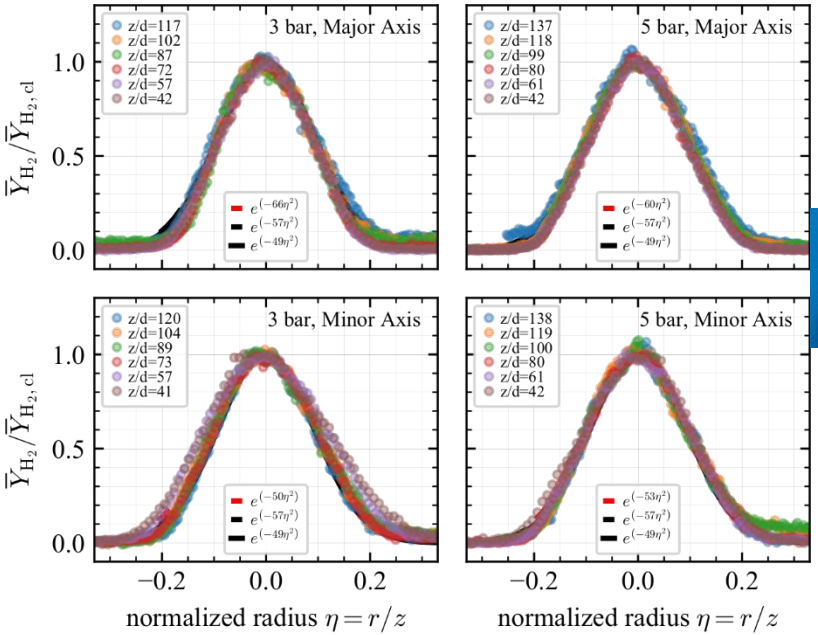


Self-similar temperature fields were also measured

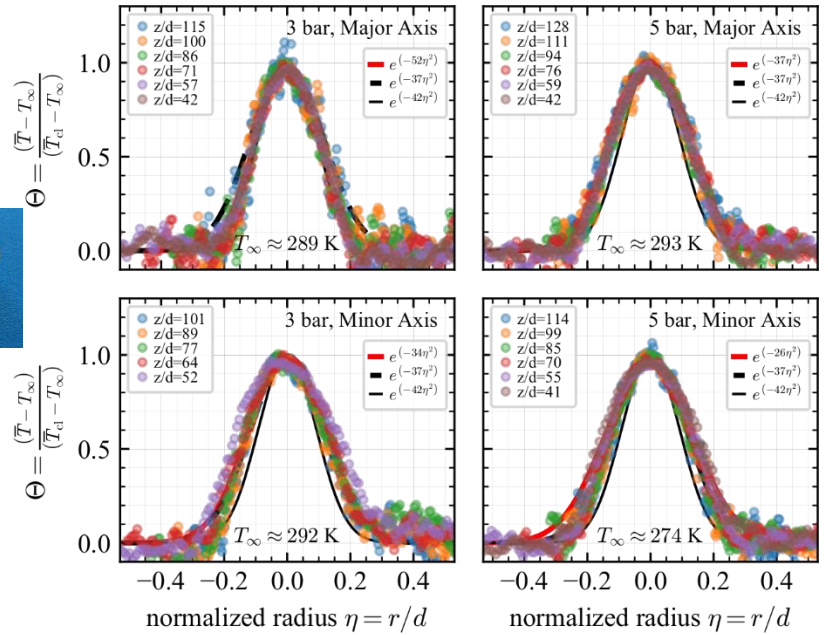


Real leaks will likely not be round, so an experimental campaign was completed with high aspect ratio nozzles

Aspect ratio 32

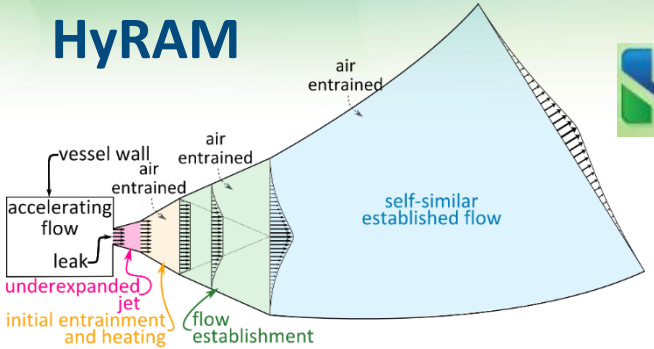


Aspect ratio 32

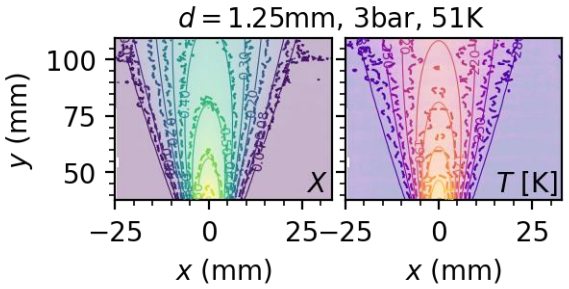


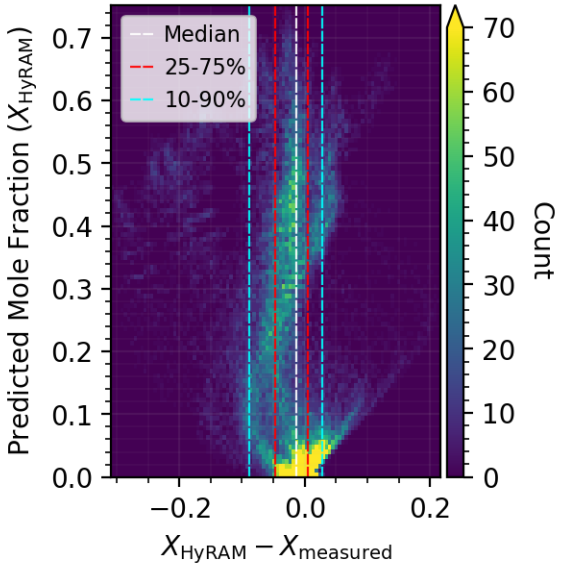
- No significant difference were observed (self-similar, Gaussian profiles) between high aspect-ratio nozzles and round nozzle profiles

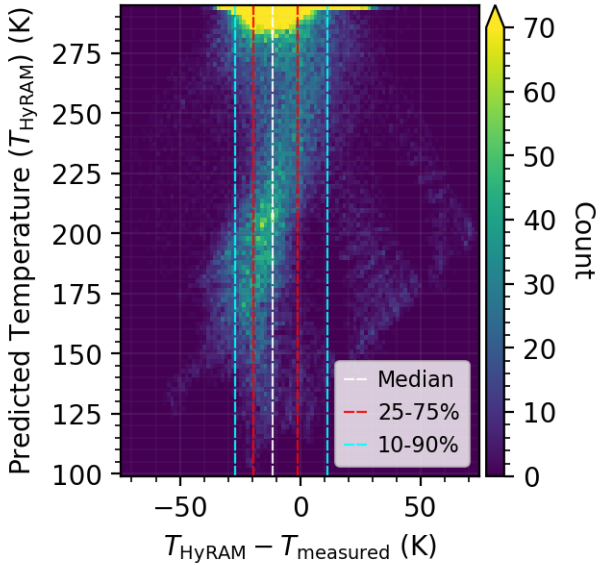
We have used lab-scale data to validate the dispersion model in HyRAM



HyRAM
HYDROGEN RISK ASSESSMENT MODELS



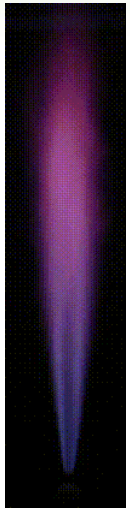




- Mole fraction and temperature predictions slightly lower than those measured but reasonably accurate

Summary and conclusions on lab-scale dispersion

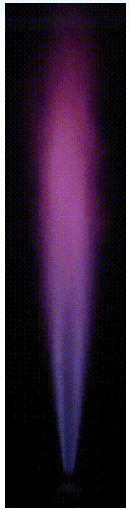
- Used advanced imaging diagnostics (planar laser Raman imaging) to measure cryogenic hydrogen mixing with air and warming
- Centerline mass fraction decay rate for cryogenic hydrogen similar to warm hydrogen
- Centerline temperature also increases linearly against normalized distance
- Mass-fraction (and temperature) profiles are self-similar, Gaussian, and slightly wider than for ambient temperature hydrogen
- Concentration and temperature fields of dispersion from AR 16 and 32 nozzles is the same as for round nozzles under these conditions (1 mm equivalent diameter, ≈55 K, 3 and 5 bar_{abs})
- Simulations using dispersion model in HyRAM are accurate, for round or even for high aspect-ratio release geometries
- Data from experiments is available upon request (*SAND2019-2199 O, SAND2020-3950 O)*



QUESTIONS

COMMENTS

DISCUSSION



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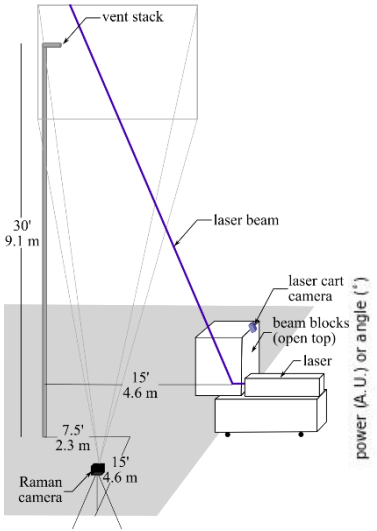
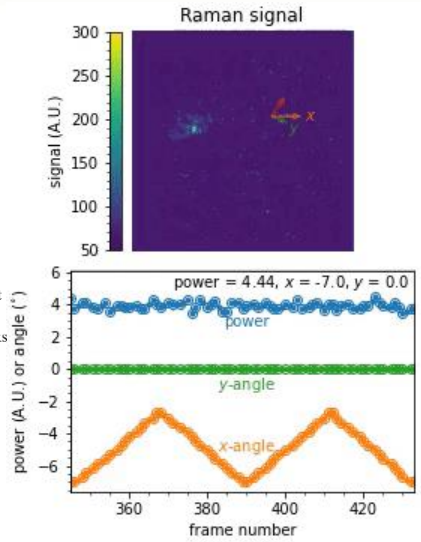
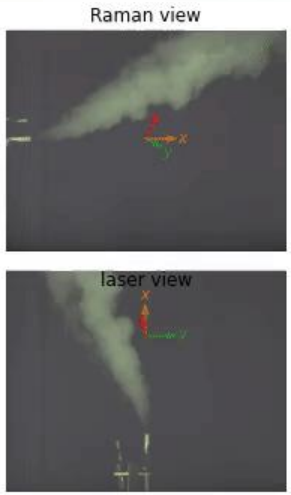
- Industry support including the OEM Group at the California Fuel Cell Partnership, Linde, and Shell
- Air Liquide and partners

More recently, we have demonstrated use of the Raman diagnostic for larger releases







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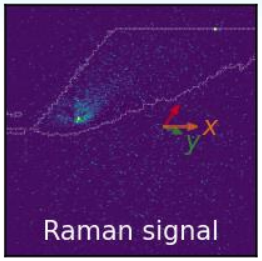
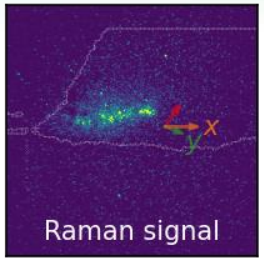
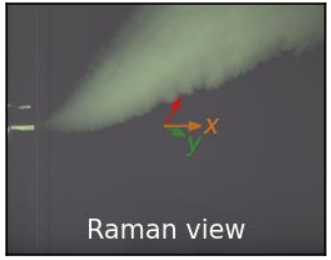
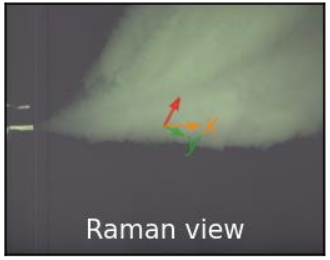
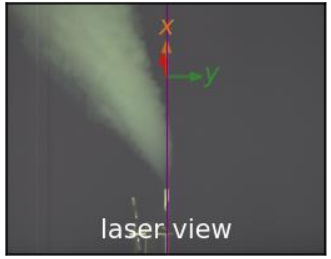
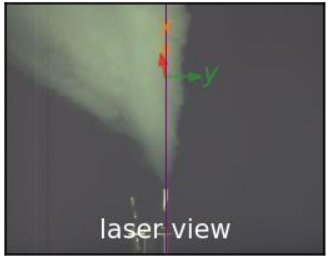








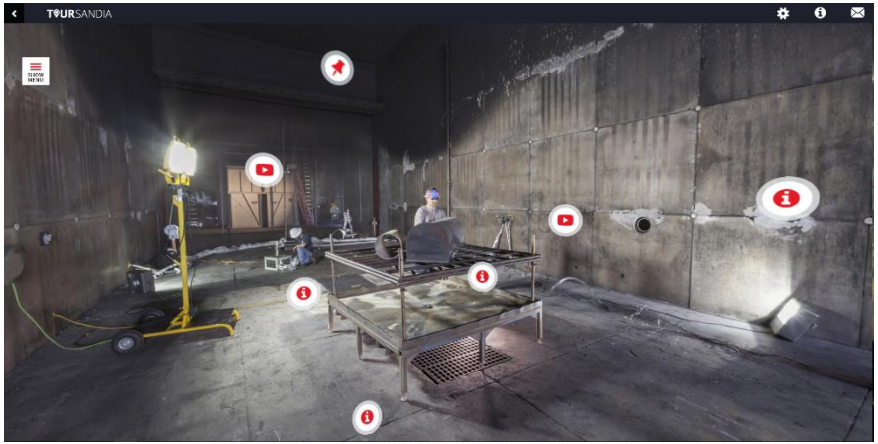




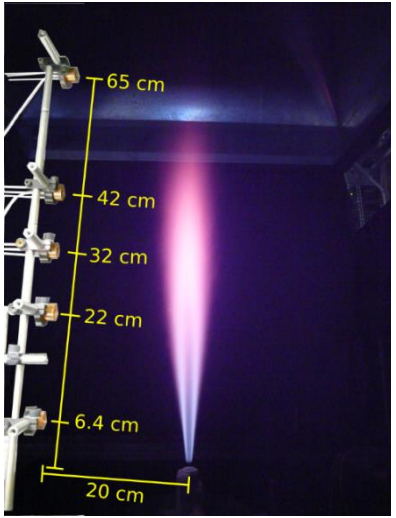
- As wind blows the visible plume off, then back on of the laser-line, the Raman signal disappears, then increases

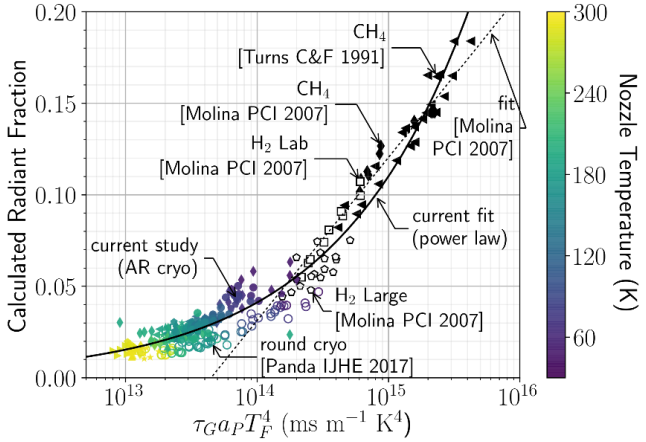
We are planning additional experiments to understand other phenomena related to liquid hydrogen

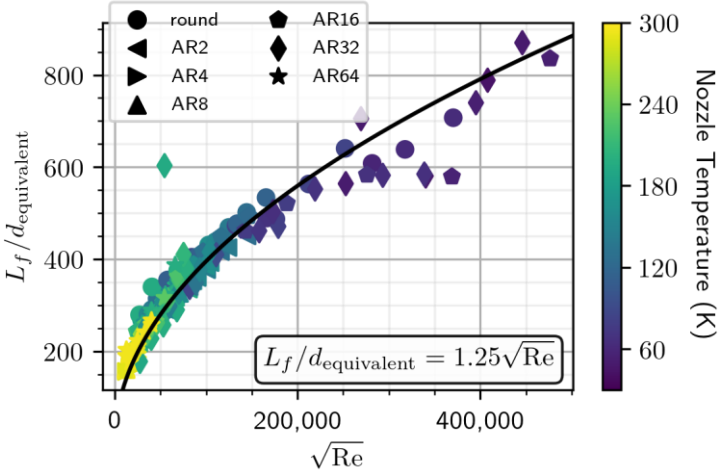
- Additional experiments are needed to address additional phenomena:
  - Controlled experiments at Sandia's Cross-Wind Test Facility to validate models for:
    - Pooling
    - Evaporation from LH_2 pools
  - Revisit mitigation from walls, including dispersion and mitigation of liquid hydrogen leaks/flames
    - Effects on unignited dispersion and accumulation
    - Reduction in heat flux/overpressure
  - Partner with others, applying diagnostic at remote locations (European colleagues, CGA G-5.5 testing task force) and analyze external data



Lab-scale experiments on flames from round and high aspect ratio nozzles have been used for model validation



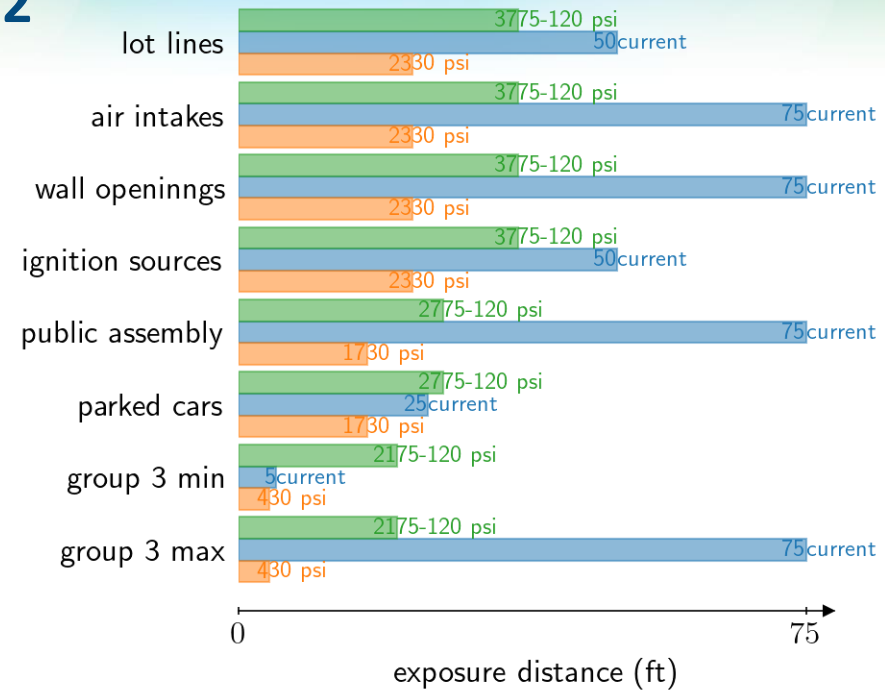




- No clear aspect-ratio dependence for radiant fraction or flame length
- All data collapses onto a single curve for warm and cryogenic temperatures

We have used HyRAM models to propose new liquid hydrogen exposure distance tables for NFPA 2

- Proposal submitted to first draft of NFPA 2
- Providing additional justification for subsequent revisions to code
- Separation distances grouped same as gaseous distances
- Distances function of pipe size and system pressure instead of tank volume
- Safety factor of 2 included to account for uncertainty (safety factor of 1.5 used for gaseous distances)



➢ Most distances reduced for typical pipe size (1.5”) and operating pressure (vs typical tank volume); some increase (but mitigations, i.e. walls can be used)