Sandia National Laboratories

Exceptional service in the national interest

Experimental research on cryogenic hydrogen behavior at Sandia National Laboratories

Ethan S. Hecht

ELVHYS 2nd workshop on safety of cryogenic hydrogen transfer technologies

November 29, 2023

SAND2023-14034C

SANDIA IS A FEDERALLY FUNDED RESEARCH AND DEVELOPMENT CENTER (FFRDC) MANAGED AND OPERATED BY

National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc.

Government-owned, contractor-operated

FFRDCs are long-term strategic partners to the federal government, operating in the public interest with objectivity and independence and maintaining core competencies in missions of national significance

WE HAVE FACILITIES ACROSS THE NATION

Main Sites
Albuquerque, New Mexico
Livermore, California

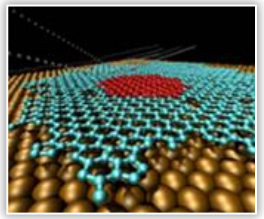
SANDIA R&D FOCUS IS ON MATERIALS AND SAFETY

Sandia provides deep, quantitative understanding and a scientific basis for….

***Materials* – for hydrogen production, storage, delivery, conversion and utilization**

***Safety* – risk analysis and the creation of risk-informed standards**

Hydrogen Production



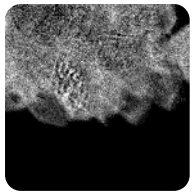
Discovery of advanced water-splitting materials for large-scale H_2 production

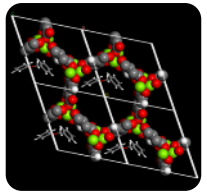
HydroGEN
Advanced Water Splitting Materials

Hydrogen Storage

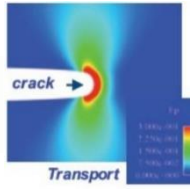
Discovering the behavior and performance of solid storage materials

HyMARC
Hydrogen Materials Advanced Research Consortium





Hydrogen Delivery

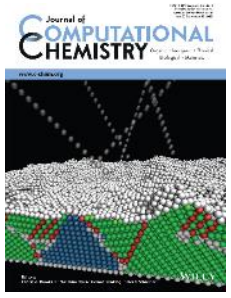


HyBlend
U.S. DEPARTMENT OF ENERGY

Fuel Cells

Develop new membrane systems for enhanced electrochemical performance

Materials Compatibility



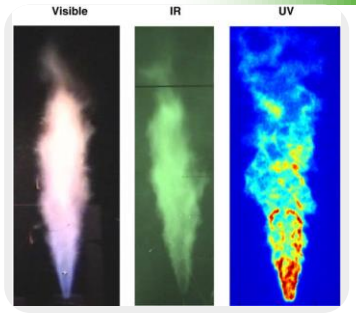
Elucidation of hydrogen embrittlement phenomena at the atomistic scale

H-Mat℠
Hydrogen Materials Compatibility Consortium

Systems Engineering

Hydrogen for marine, rail, and aviation

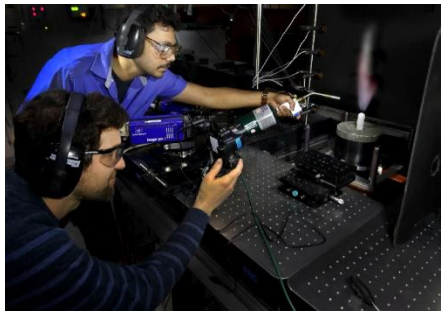
Safety, Codes & Standards



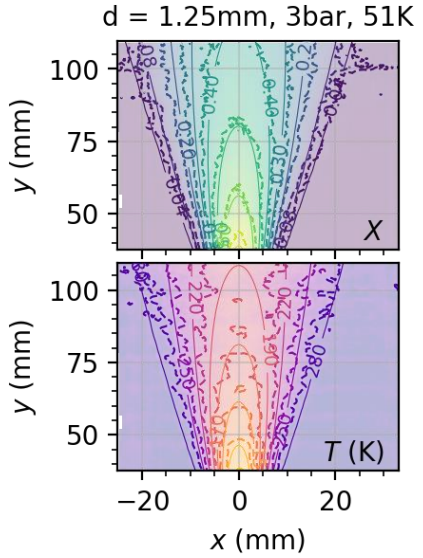
State-of-the-art characterization of thermophysical & thermochemical behavior of H_2 integrated with Bayesian theory

HyRAM+
Hydrogen Plus Other Alternative Fuels Risk Assessment Models

Sandia's H_2 safety codes and standards program has coordinated activities that facilitate deployment of hydrogen technologies



Hydrogen Behavior:
Develop and validate scientific models to accurately predict hazards and harm from liquid releases, flames, etc.



problems

analysis

HyRAM+
Hydrogen Plus Other Alternative Fuels Risk Assessment Models

models

model needs

Enable Hydrogen Infrastructure through Science-based Codes and Standards
Apply QRA and behavior models to real problems in hydrogen infrastructure and emerging technology

problems

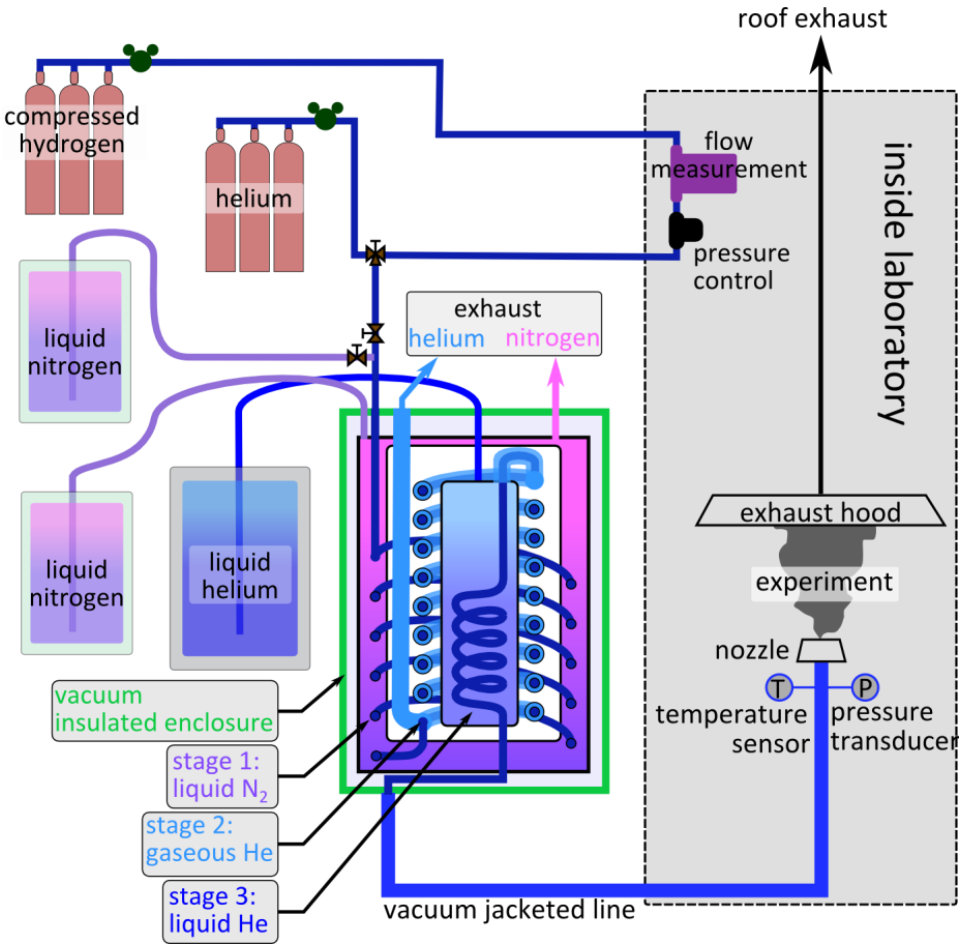
analysis

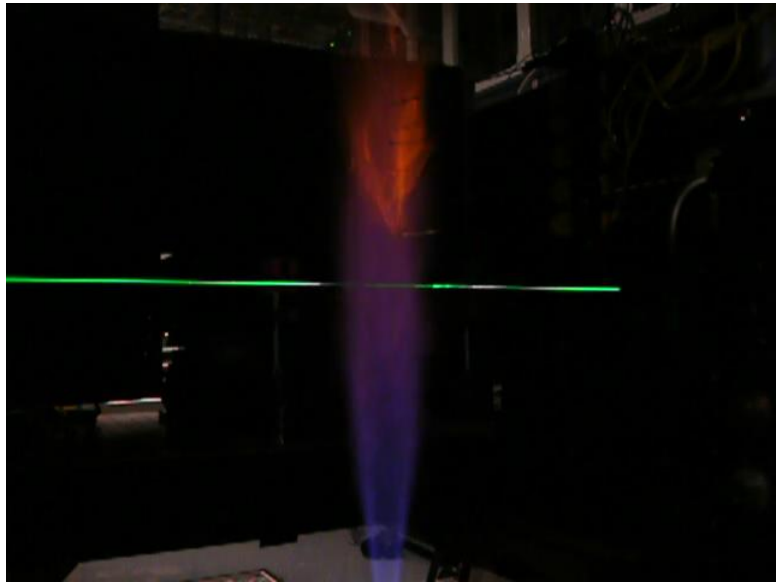
Quantitative Risk Assessment, tools R&D:
Develop integrated methods and algorithms enabling consistent, traceable, and rigorous QRA (Quantitative Risk Assessment) for H_2 facilities and vehicles

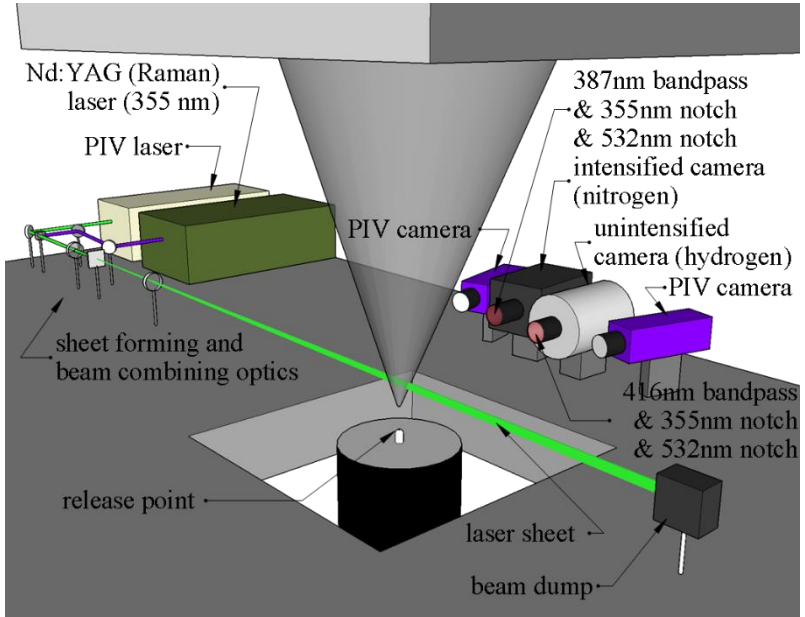
https://hyram.sandia.gov

We developed a cryogenic release platform inside the laboratory for small-scale releases

P = 1 bar, d= 1mm, T = 37 K, distance = 325 mm



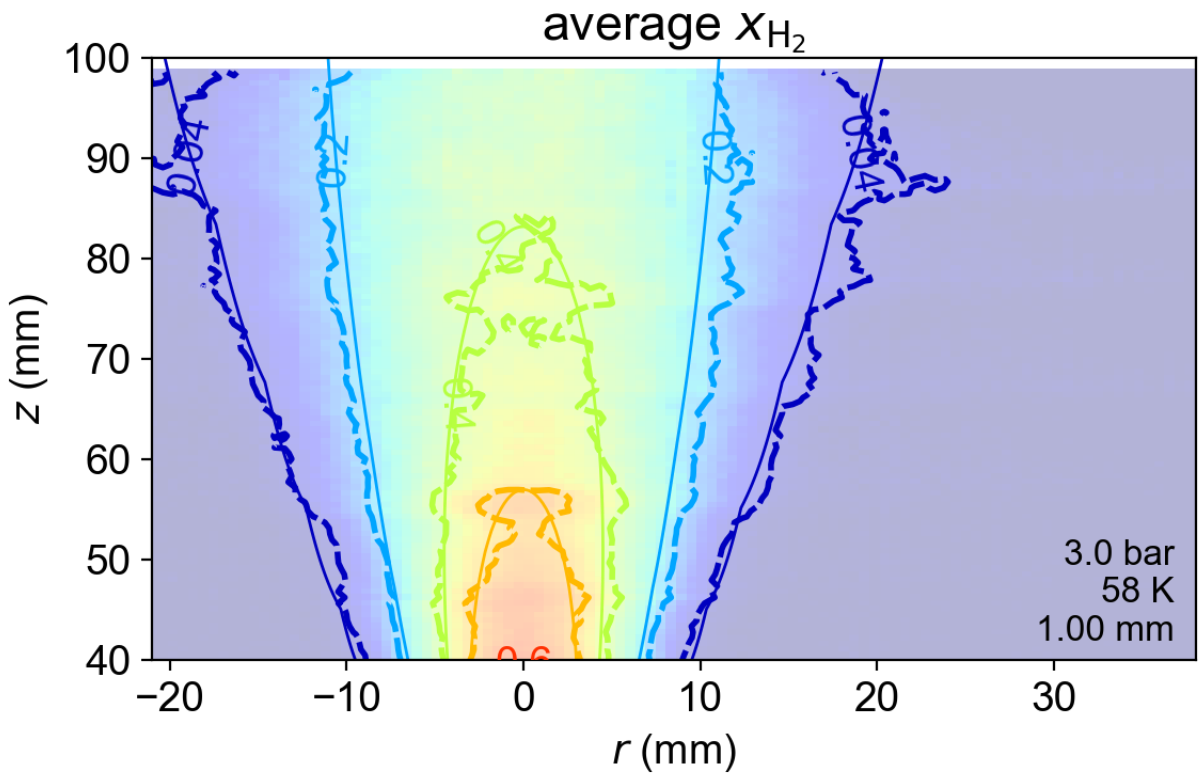


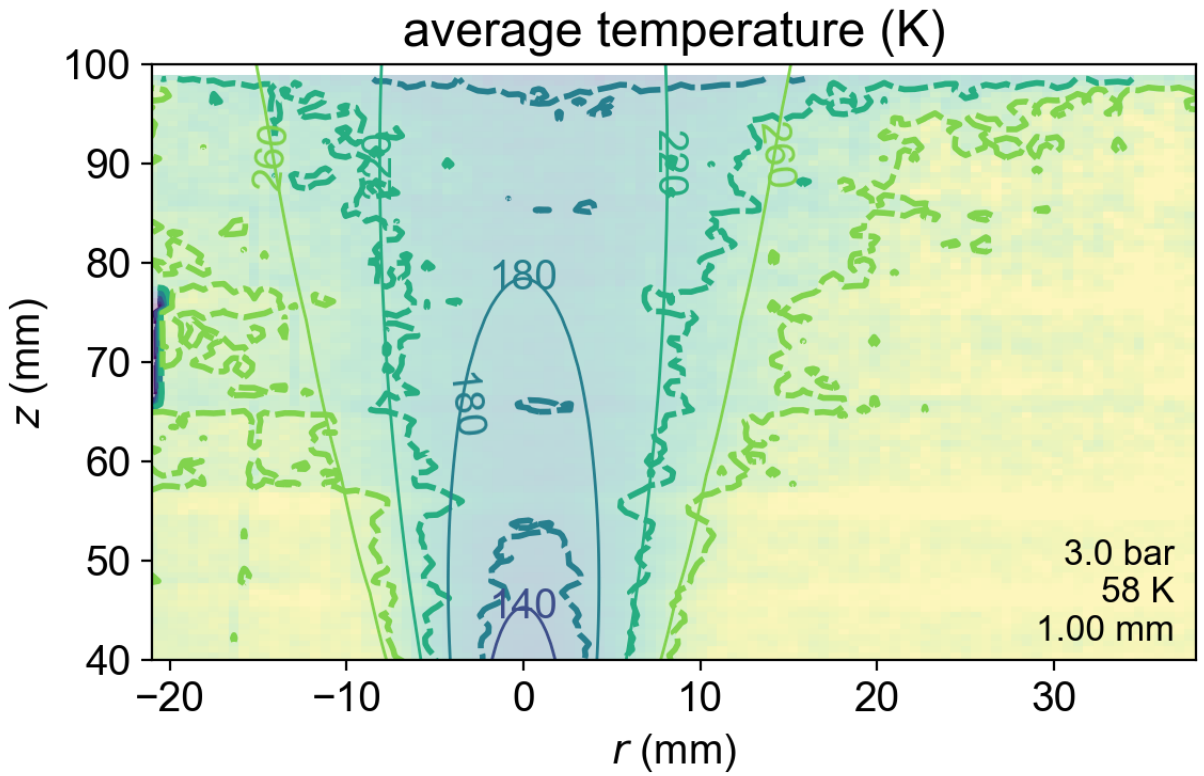


Enables studies of:

- Dispersion
- Ignition
- Heat transfer

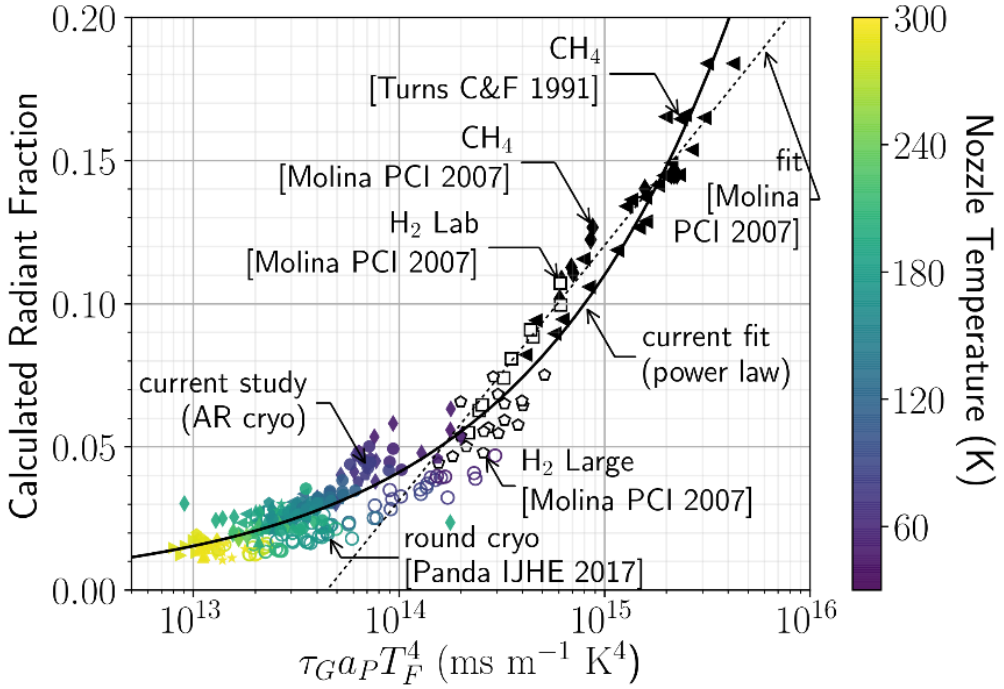
Measurements of dispersion from round releases have been used to validate models





- Experiment: thick, dashed lines and shading
- Model: think, solid lines

Radiant fraction data was shown to collapse onto a single curve, regardless of aspect ratio, temperature, or even fuel



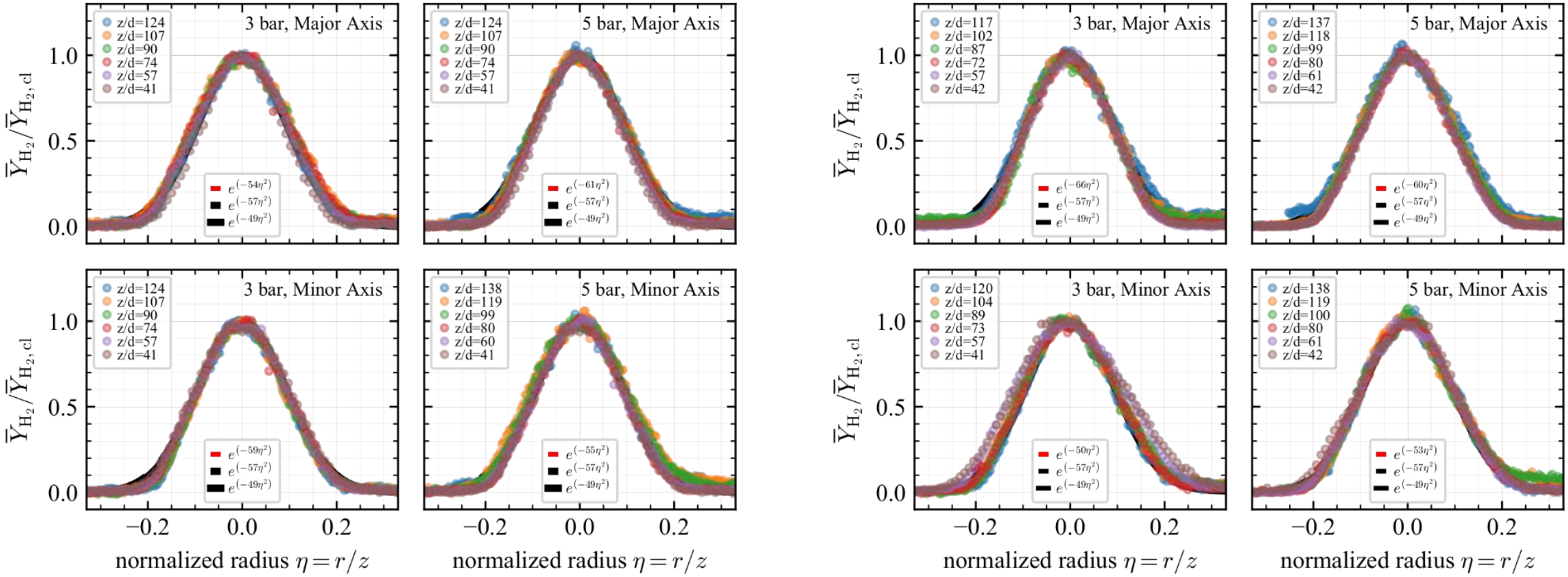
$$X_{rad} = 2.33 \times 10^8 \left(\tau_g a_P T_f^4\right)^{0.44}$$

- Radiant fraction for hydrogen lower than for methane
- No clear aspect-ratio dependence
- All data collapses onto a single curve

At moderate distances downstream (40 diameters), concentration profiles are the same along the major and minor axes

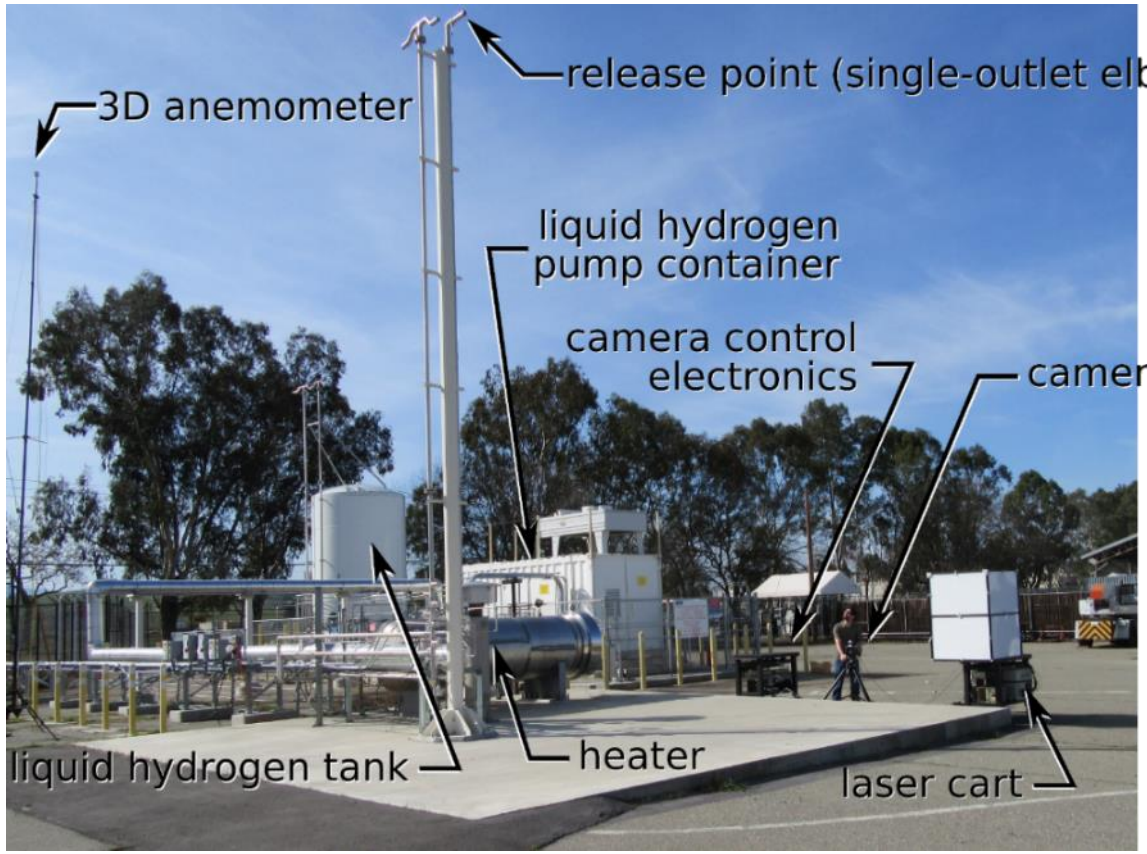
Aspect ratio 16

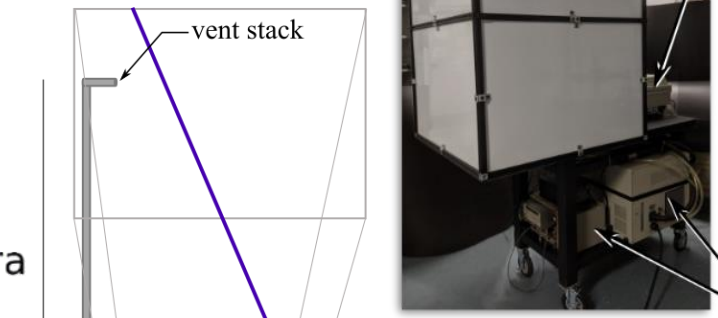
Aspect ratio 32

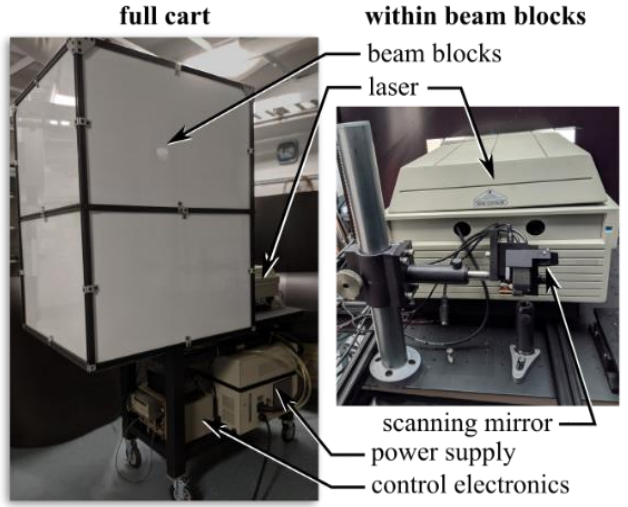


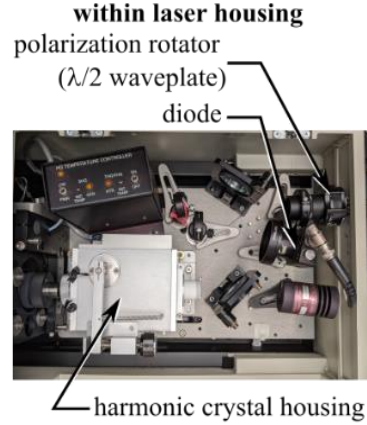
- Concentration profiles are Gaussian and self-similar
- No significant difference between high aspect-ratio nozzles and round nozzle profile

A mobile laser scanning system was developed for outdoor use and deployed at the LLNL liquid hydrogen pad





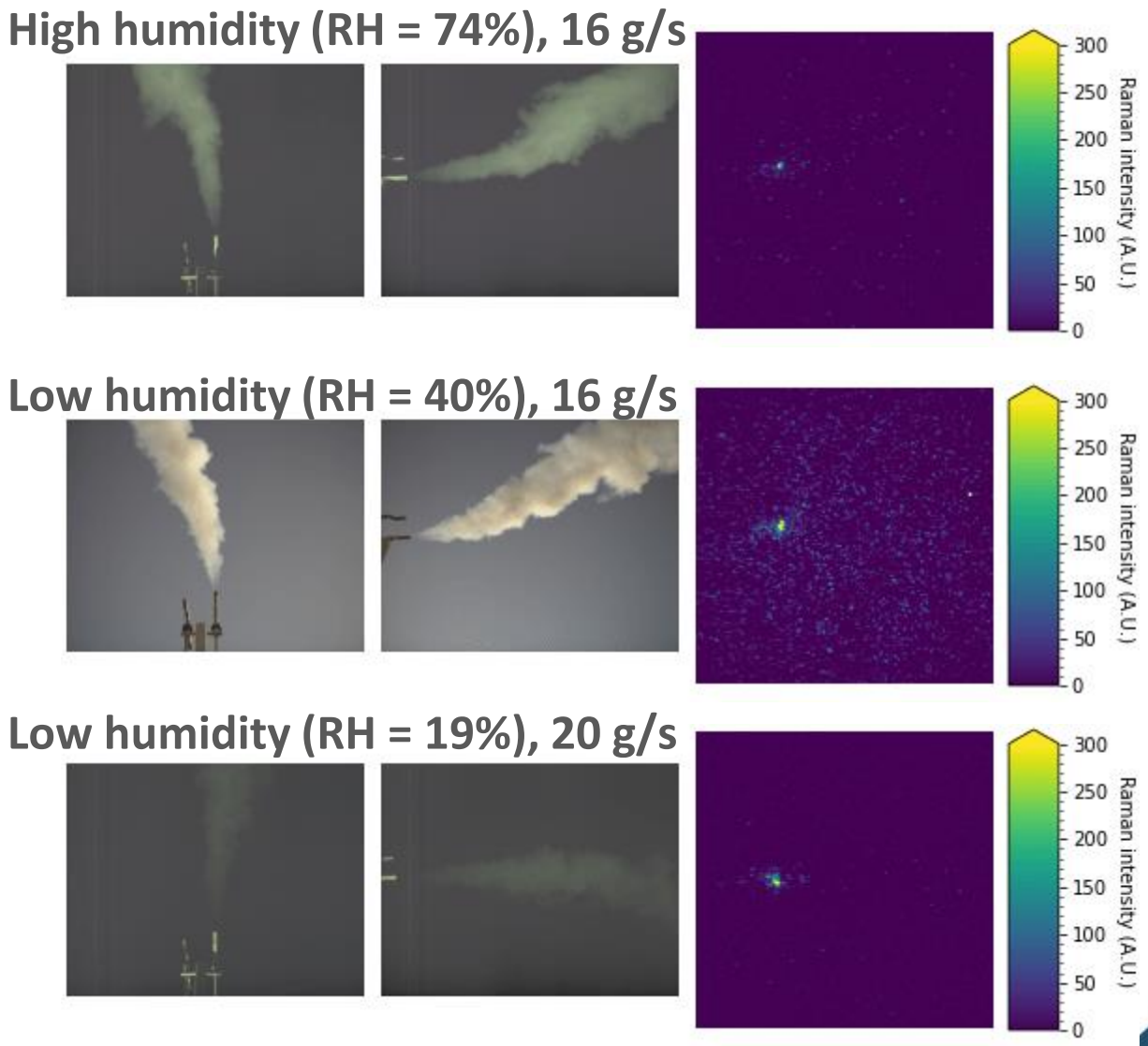




Experiments demonstrated that humidity has little effect on hydrogen/visible plume trajectory

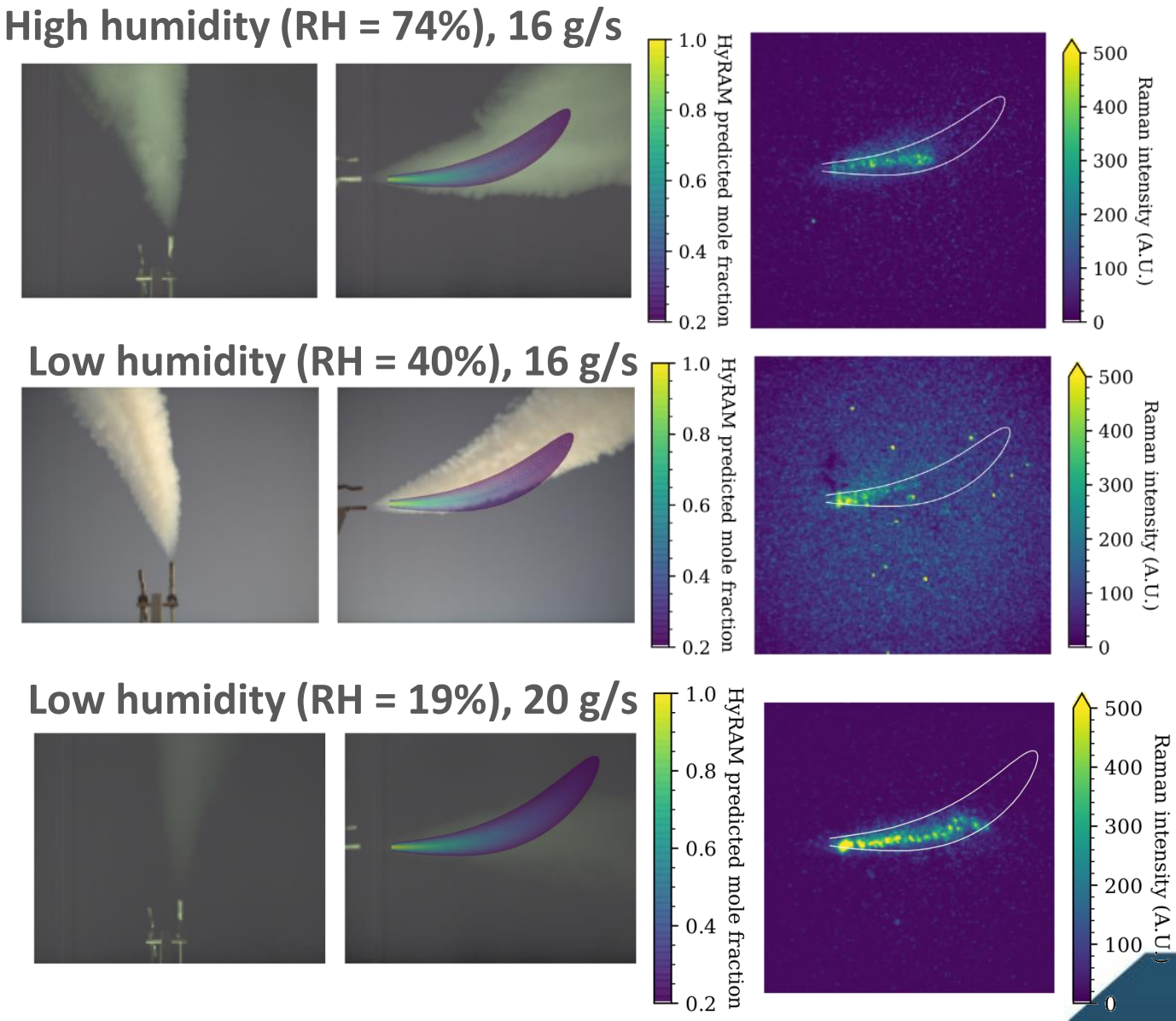
- Additional humidity does not lead to larger (wider) visible plume
- Buoyancy not affected by humidity (trajectories similar)
- Raman signal similar for all (19-74%) relative humidity

➢ Condensation of water vapor has minimal influence on dispersion



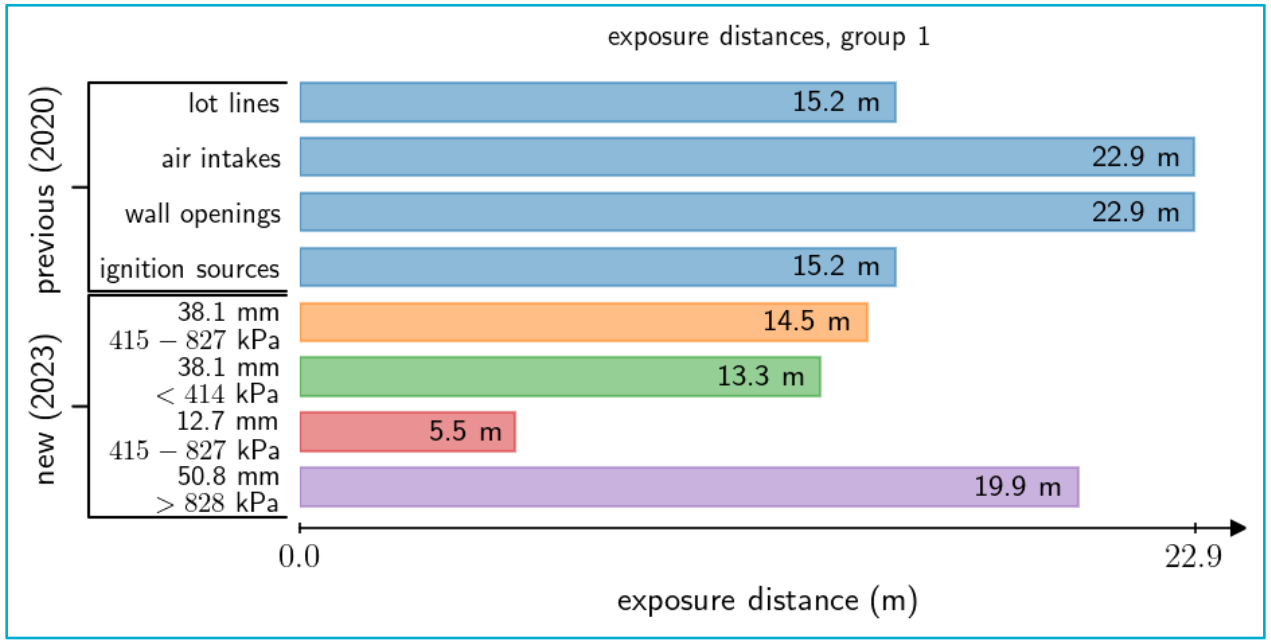
Qualitative comparisons show good agreement to the model predictions

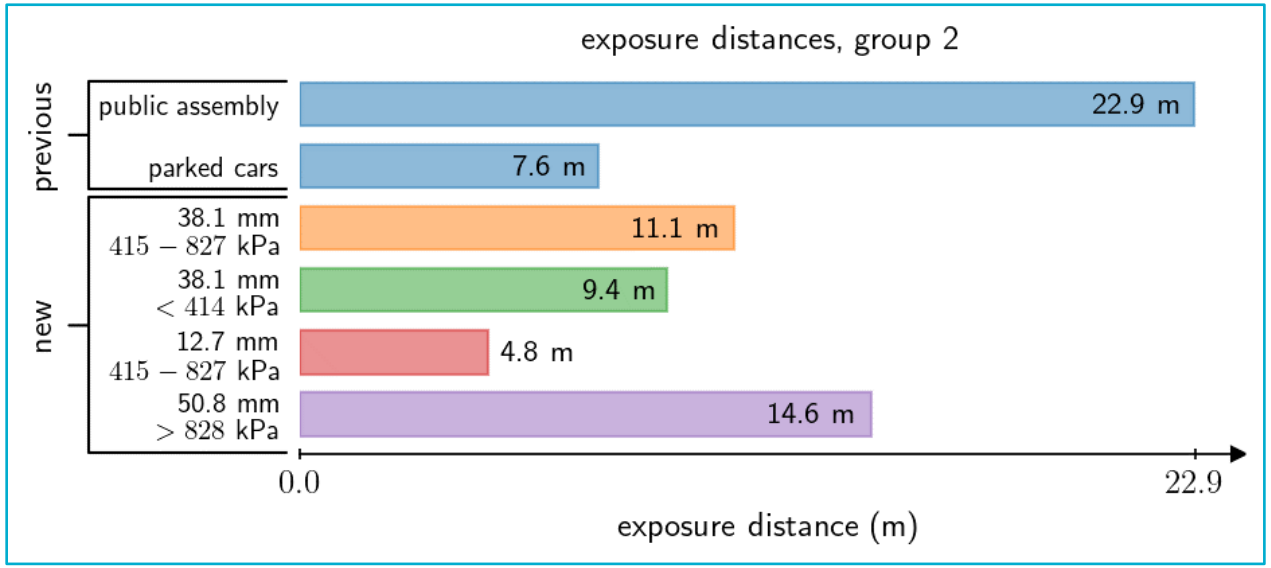
- Predicted trajectory slightly less buoyant for lower flow rate and slightly more buoyant for higher flow rate
  - Trajectory also affected by light winds
- Raman signal nearly all falls within predicted 20% mole fraction contour shown in white
- Challenges quantifying small Raman signal with shifting winds

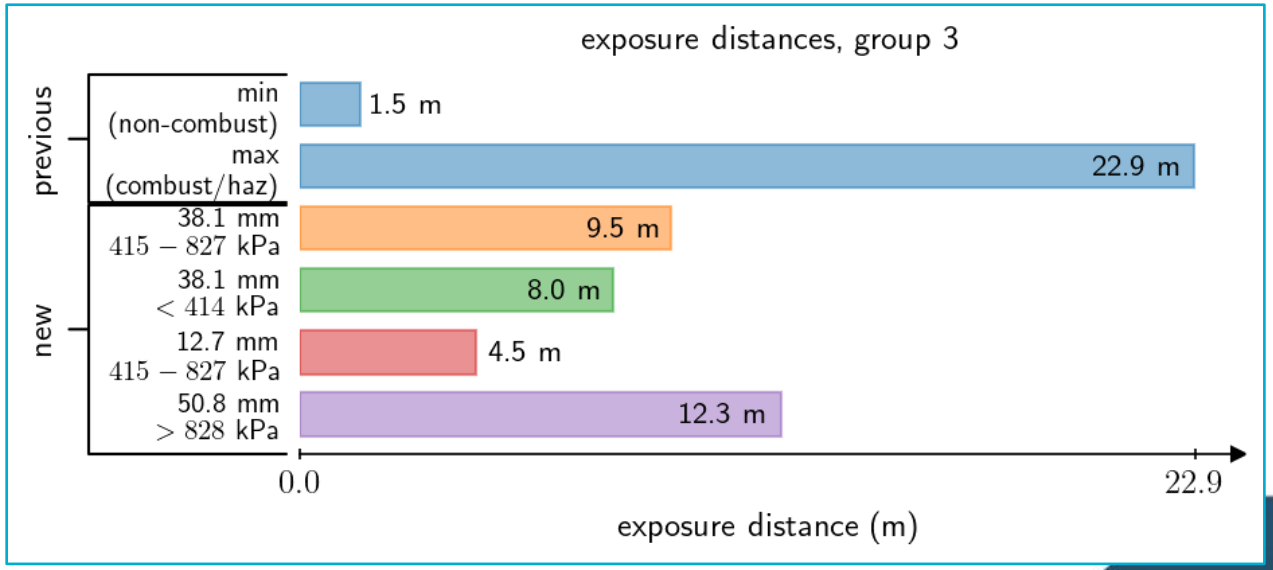


Validated models from HyRAM+ were used to update the 2023 edition of NFPA 2 for bulk liquid hydrogen

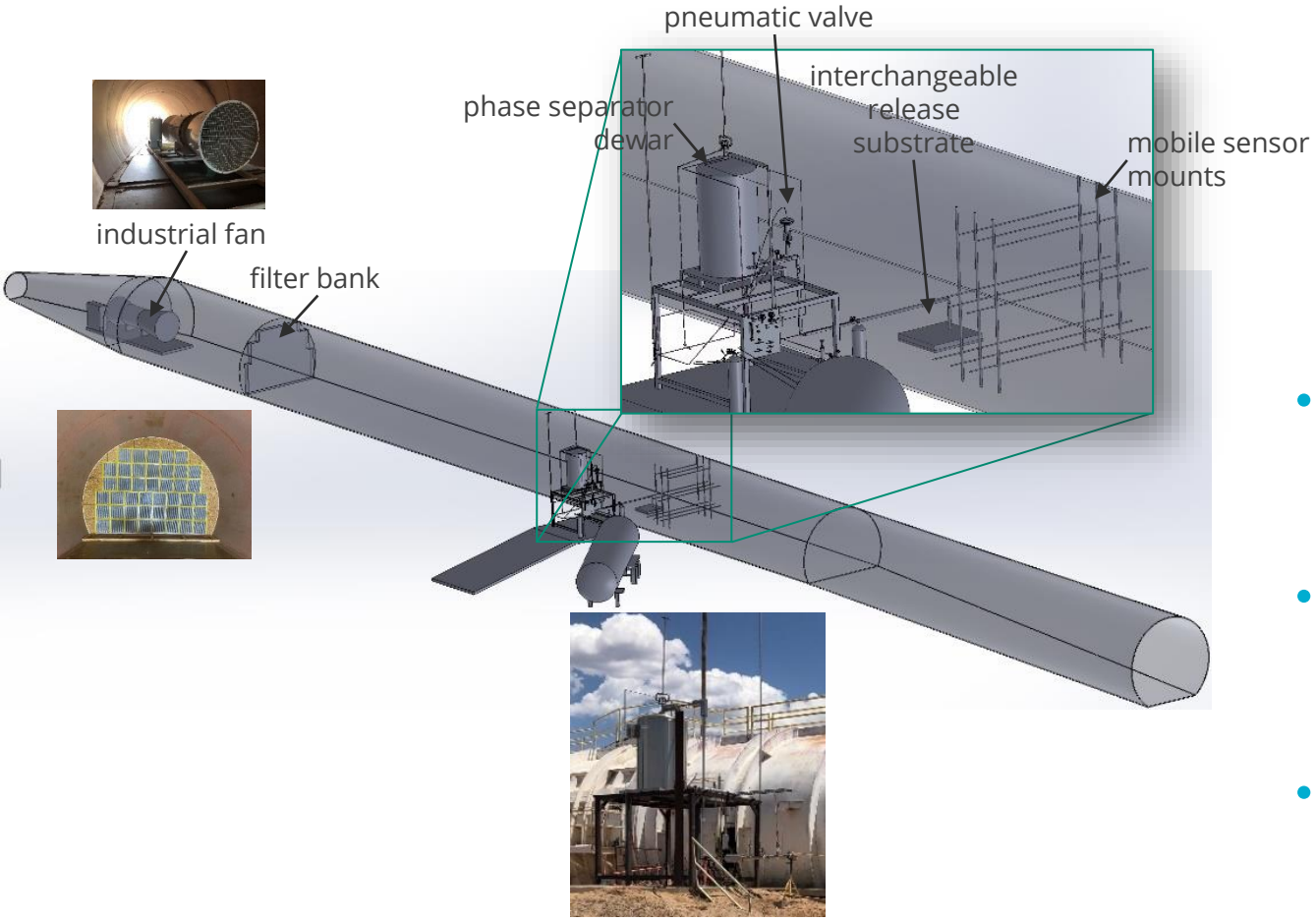
- Consequence-based distances from dispersion, heat flux, and unconfined overpressure criteria
- Distances are most often reduced for group 1 exposures
- Distances for group 3 exposures are increased in many cases
- Distances can be reduced through the use of fire-barrier walls and welded, vacuum-insulated piping







Upcoming liquid hydrogen pooling and vaporization experiments will enable additional development of science-based codes and standards



- Experiments will measure extent of pooling and vaporization rate for various controlled cross-winds
- Using thermocouples and HyWAM sensor array (in collaboration with NREL) for concentration measurements
- Pooling and heat flux measured with visible and IR cameras and embedded thermocouples

➢ Data will be well suited for model validation, with careful control of boundary conditions

Summary and conclusions

Sandia has coordinated experimental and modeling activities on cryogenic hydrogen

- HyRAM+ contains reduced order models for compressed and cryogenic hydrogen
- Laboratory experiments using a heat exchanger and releases through small nozzles
  - Data on flames and dispersion used to validate models
  - Little difference observed between high-aspect ratio releases and round releases
- Outdoor vent-stack release experiments measured larger releases
  - Condensation of water vapor has minimal influence on dispersion
  - Challenges quantifying small Raman signal with shifting winds
- Upcoming experiments to study pooling and vaporization
- Models from HyRAM+ were used to update the 2023 edition of NFPA 2 for bulk liquid hydrogen

Thank you!

Questions?

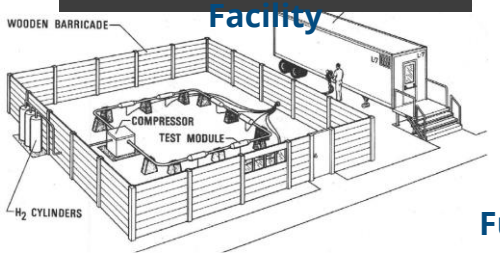
ehecht@sandia.gov

SANDIA HAS FIVE MAJOR PROGRAM PORTFOLIOS

SANDIA IS BUILDING CLIMATE SECURITY THROUGH SCIENCE, TECHNOLOGY AND ACTION

- Advance the state of the art within three climate focal areas: measurement and modeling, clean energy and processes, and resilient infrastructure
- Apply climate expertise to strategic cross-cutting issues including risk assessment and decision support, intervention, arctic science and security, mitigation and adaptation, and treaty monitoring and verification
- Develop cutting-edge R&D facilities like a next generation concentrating solar power plant and climate security analysis center
- Model the way forward in site sustainability with the goal of net-zero emissions at Sandia/California by 2040 and Sandia/New Mexico by 2045

Decades of Hydrogen Research at Sandia



Experimental Hydrogen Pipeline Facility

Fusion Energy Sciences

Conference Organization

METAL HYDRIDE CENTER OF EXCELLENCE

Lift-Truck Lifecycle Requirements

Mobile Lighting

SHASTA
Subsurface Hydrogen Assessment, Storage, and Technology Acceleration

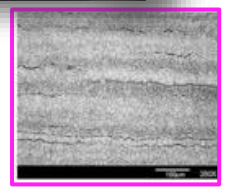
Solar Thermo-Chemical Hydrogen

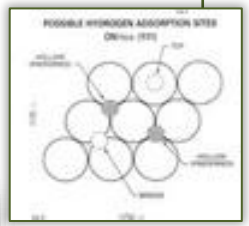
HydroGEN
Advanced Water Splitting Materials

1960 1970 1980 1990 2000 2005 2010 2015 2020 2023

Metallurgy

Tritium Research



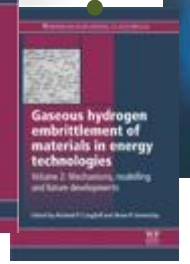


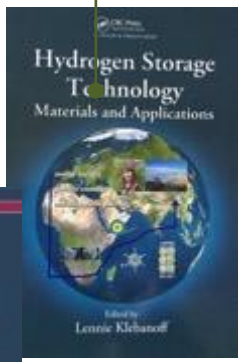
Embedded Atom Method

RATLER

Mining Locomotive

Automotive Storage





HyBlend
U.S. DEPARTMENT OF ENERGY

H-Mat
Hydrogen Materials Compatibility Consortium

HyRAM+
Hydrogen Plus Other Alternative Fuels Risk Assessment Models

HyMARC

Roll-to-Roll Consortium