Guidance for Indoor H_2 Sensor Placement

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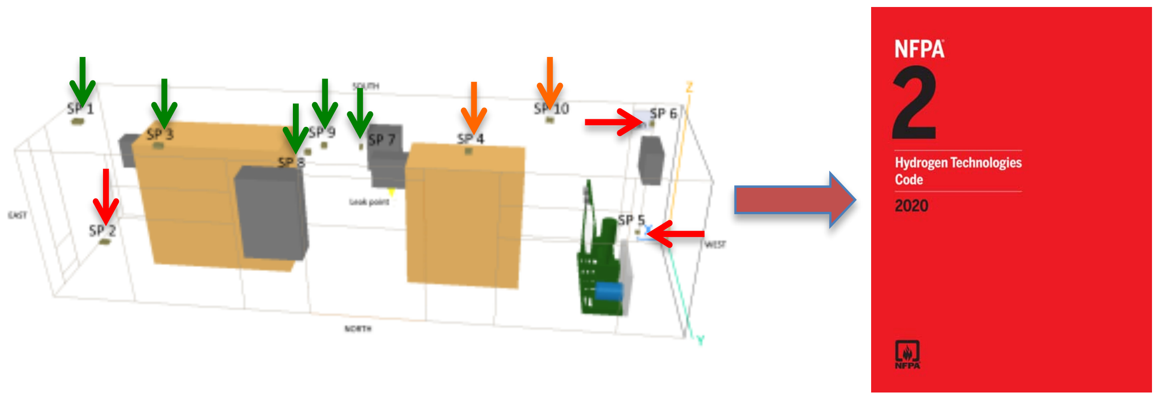

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Project ID # SCS027

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Project Goal

- Disseminate guidance for hydrogen sensor placement via informing the next revision of NFPA 2 and developing new text for Annex M3 “Location of Gas Detectors to Effectively Detect Hydrogen”.
- Develop CFD-informed examples in HyRAM physical effects mode for ventilated enclosures by uploading CFD data on flammable concentrations distribution for horizontal and vertical releases into the layer model for more realistic over pressure calculations.
- Demonstrate applicability of developed hydrogen sensor placement guidance to outdoor high-pressure hydrogen storage cabinets.

Proper sensor placement for early leak detection improves public safety

Overview

Timeline

- Project start date: 02/12/2019
- Project End Date: 07/09/2021
- ❖ Project continuation and direction determined annually by DOE

Budget

- FY19 DOE funding: $ 75,000
- FY20 DOE funding: $ 75,000
- FY21 planned DOE funding: $ 75,000
- Total DOE funds received to date: $ 225,000

Barriers

A. Safety Data and Information: Limited Access and Availability

G. Insufficient Technical Data to Revise Standards

K. No Consistent Codification Plan and Process for Synchronization of R&D and Code Development

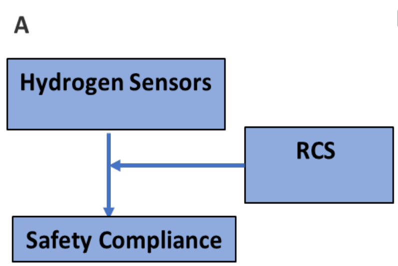
Partners

- A.V. Tchouvelev & Associates Inc.
- NREL

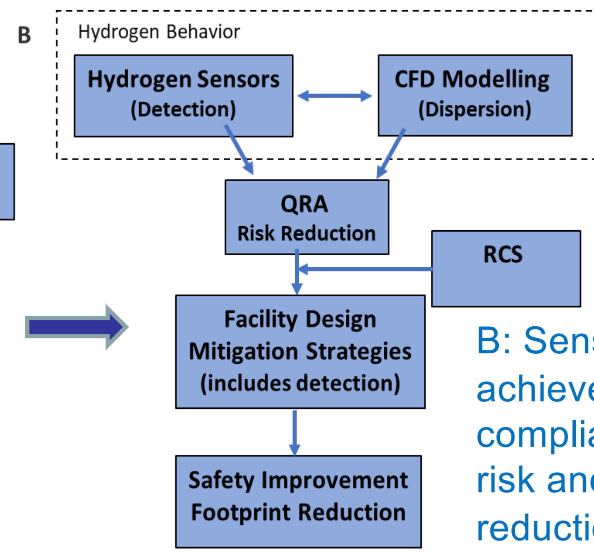
Relevance

- ❑ Objective: Enable the safe use of hydrogen as an alternative renewable fuel via a cost-effective and smart hydrogen detection system
  - ➢ Provide rational guidance on hydrogen sensor deployment strategies to mitigate risks and minimize hazards associated with the inadvertent release of hydrogen.

Evolution of the role of sensors: From A to B



A: Sensors to achieve RCS compliance



B: Sensors to achieve RCS compliance and risk and footprint reduction

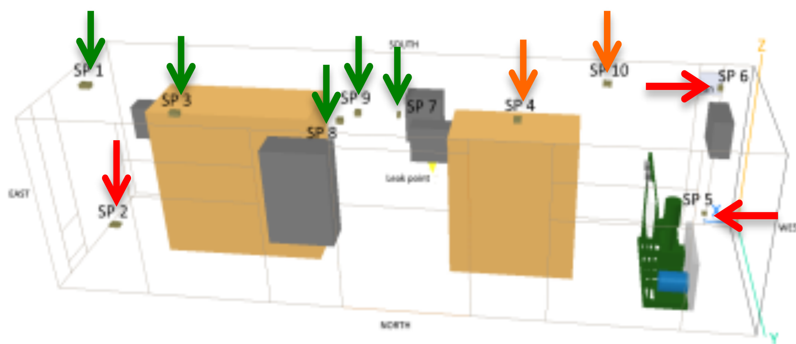
Active monitoring for early leak detection is one mitigation strategy to assure facility safety

Approach – Task 1

- ❑ Dissemination of the sensor placement guidance document:
  - ➢ Collaboration with NFPA 2 Technical Committee
  - ➢ Submission of technical content for modification of Annex M3 “Location of Gas Detectors to Effectively Detect Hydrogen” for NFPA 2 2023 revision cycle

✓ Not on direct path of airflow

✓ Practical detection range 1,000 – 4,000 ppm (0.1 to 0.4 % vol. in air)



H2 sensor placement guidance developed and validated within FY2019-2020.

NFPA 2 2023 Revision cycle

H_2 sensor placement guidance document submitted to update relevant NFPA 2 content

Accomplishments and Progress – Task 1

- Approved (underscored and ~~struck out~~) modifications to NFPA 2 Annex M3 "Location of Gas Detectors to Effectively Detect Hydrogen"

The following should be considered to effectively locate gas detectors (sensors) where they are most likely to detect an unintended hydrogen release:

(1) Hydrogen buoyancy, particularly at low concentrations has limited effect on hydrogen distribution inside an enclosure. Hydrogen distribution is mostly dependent upon level of confinement and air circulation inside an enclosure. ~~which dictates that sensors should be placed above any potential release point.~~

(2) Proper ventilation designs favour ~~A~~ gas detector mounting ~~on~~ near the ceiling avoiding obstructions such as lights, piping and other objects. ~~should be avoided because of elevated temperatures at the ceiling.~~ Gas detectors should be mounted to ensure low turbulence around the sensor head a foot or more below the ceiling - possibly using the wall.

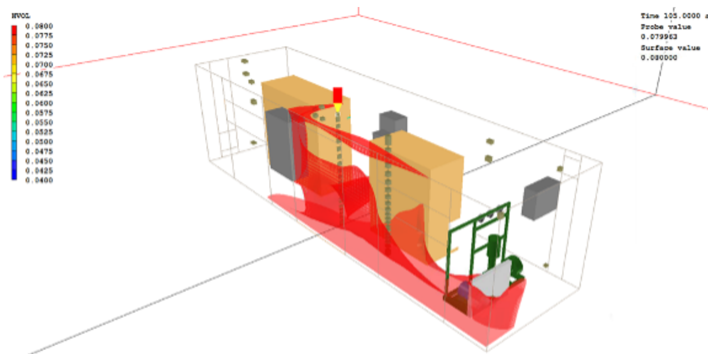
(3) The gas detector should have an effective range of 1000 to 4000 ppm(v) to be effective for early detection. ~~be mounted facing the potential release point. However, considerations should be given to the effect ventilation would have on air flow and how this alteration of air flow might impact the direction or orientation of the release point.~~

(4) The gas detector should not be ~~effectively downwind of any~~ on the direct path of any potential air flow from the air inlet to the exhaust fan to avoid sensitivity to air flow variations and dilution. Placement inside air exhaust ducts should be avoided.

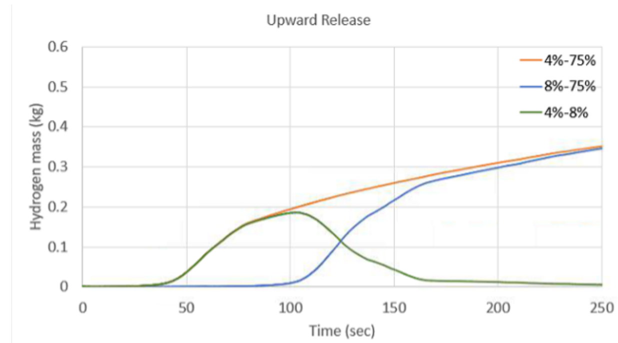
NFPA 2 Technical Committee agreed with major findings regarding sensor placement guidance

Approach – Task 2

- Incorporate CFD results into HyRAM enclosure layer model physical effects mode and connect to QRA mode:
  - Identify realistic flammable mass between 8% and 75% vol. for horizontal and upward releases in small enclosure
  - Upload both 4%-75% and 8%-75% to HyRAM
  - Calculate and compare resulting over pressures → feed to QRA



8% vol. H_2 conc. build-up from bottom up for horizontal release in small enclosure

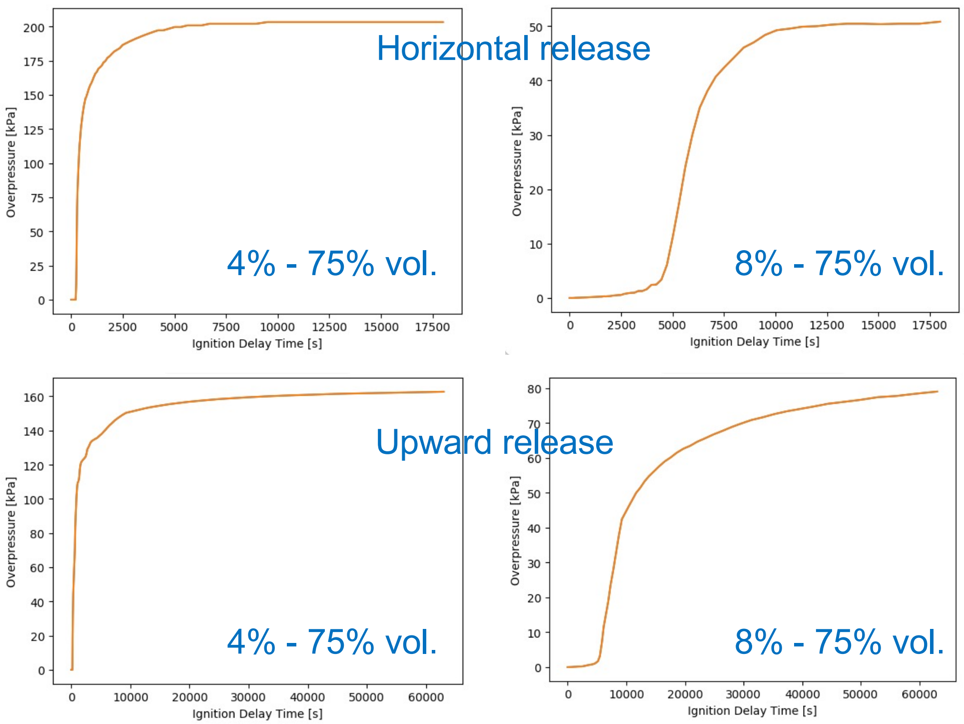


Sample data for uploading to HyRAM for upward release inside small enclosure

Uploading CFD results to HyRAM allows for more accurate input on H2 concentrations in enclosures

Accomplishments and Progress – Task 2

- ❑ Uploaded CFD results into HyRAM enclosure layer model and compared over pressures for horizontal and upward releases



Comparison of over pressures generated by HyRAM enclosure model for horizontal and upward releases for 350 bar leak from a 0.18 mm orifice in a small enclosure: use of 4%-75% vol. layer leads to exaggerated deflagration over pressure and timeline.

CFD-informed on H_2 dispersion HyRAM layer model generates more accurate over pressure calculations

Approach – Task 3

- Investigate validity of H_2 sensor placement guidance for outdoor confined environment:
  - Use the incident at NEL station in Norway in 2019 as a relevant case study
  - Use publicly available information from 'The Kjorbo Incident" analysis and NEL as sources of credible data for modeling

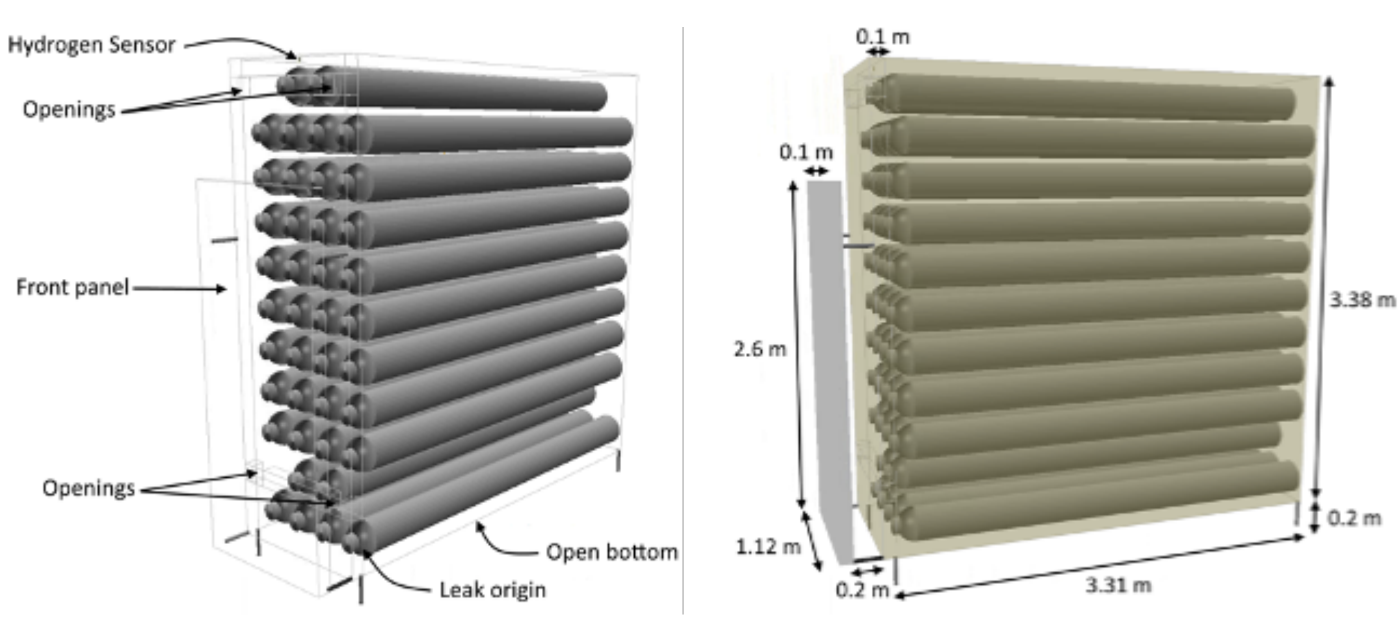
Damaged 950-bar storage vessels

Exact leak location inside the fueling storage module

CFD modeling may confirm that an H_2 sensor placed inside the module would ensure early leak detection

Accomplishments and Progress – Task 3

❑ Performed CFD modeling of calculated leak inside NEL storage module (1)

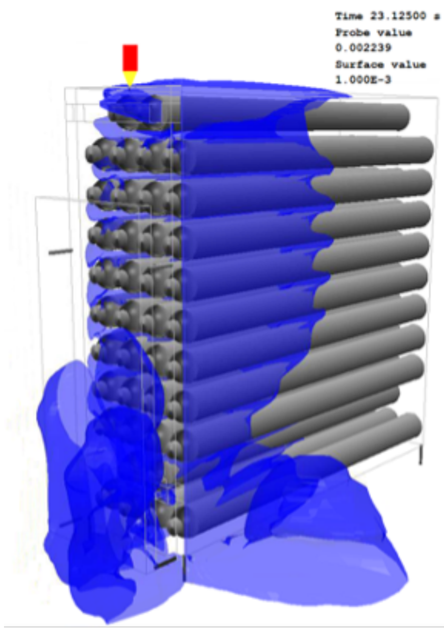


CFD modeling domain showing location of the openings and location of hydrogen sensor

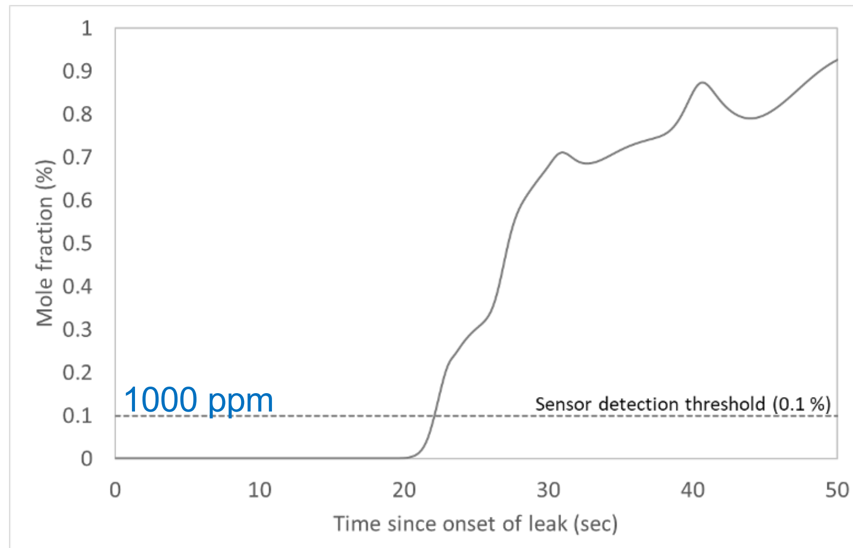
Validated CFD tool was used to build the simulation domain and perform dispersion modeling

Accomplishments and Progress – Task 3

❑ Performed CFD modeling of calculated leak inside NEL storage module (2)



Iso-surface of 0.1% vol. (1000 ppm) 23 s after the leak onset



H_2 mole fraction measured by virtual sensor at the top of the storage module

Validated CFD modeling verified that the leak could be detected within 30 s from the onset of the leak

Accomplishments and Progress:

Responses to Previous Year Reviewers' Comments

❖ *Project was not reviewed last year*

Collaborations

Collaborators:

- ❑ Sandia National Laboratories:
  - ➢ Relevant data sharing, HyRAM expertise
- ❑ NFPA 2 Hydrogen Technologies Code TC, HySafe, and PNNL Hydrogen Safety Panel:
  - ➢ Feedback on sensor placement guidance

Strong international collaborative effort

Remaining Challenges and Barriers

For sensor placement:

- ❑ Further expand to confined outdoor environment.
- ❑ Expand to cold hydrogen.
- ❑ Expand to more in-depth ventilation effects.

For enhancement of physical effects models for enclosures and risk reduction credits:

- ❑ Expand integration of CFD modeling directly into physical effects and / or QRA modes of open source HyRAM code.

Manageable challenges for both sensor placement and integration to HyRAM

Proposed Future Work*

* Project continuation and direction determined annually by DOE

1. Enhanced ventilation studies:
   a. Effect of ventilation on high-pressure leaks dispersion in hydrogen equipment enclosures (HEE) and larger indoor facilities
   b. Focus on 4%-75% vol. and 8%-75% vol. behaviour
2. Expansion to outdoor confined spaces analysis:
   a. Facilities with outdoor compressed gas and liquid hydrogen storage with fire barriers
3. Enhancement of HyRAM use for enclosures / confined spaces:
   a. Expand inventory of CFD-informed cases for more accurate over pressure calculations inside HyRAM

Critical tasks to contribute to best engineering safety practices and account for risk reduction

Summary

- Objective: Assure the safe use of hydrogen as an alternative renewable fuel via an affordable intelligent hydrogen detection system.
- Relevance: Provide rational guidance on hydrogen sensor deployment strategies to mitigate risks and minimize hazards associated with the inadvertent release of hydrogen.
- Approach: Task 1: Disseminate through code development and journal publication. Task 2: Enhance use of HyRAM for enclosures with CFD-informed layer model. Task 3: Test validity of the guidance on an outdoor compressed gas storage module.
- Accomplishments: Informed NFPA 2 2023 revision. Published in IJHE journal. Integrated three CFD-informed cases for small enclosure into HyRAM. Verified applicability of sensor placement guidance for outdoor compressed H_2 storage module.

State-of-the-Art research to validate early leak detection guidance to improve safety of H2 facilities

Technical Backup and Additional Information

Technology Transfer Activities

- No technology transfer outcomes to date

Progress toward DOE Targets or Milestones

Task 2: Research and Development

The Guidance for Indoor H2 Sensor Placement project formalized an improved strategy based on validated hydrogen dispersion models to guide use of sensors in ventilated indoor enclosures for rapid leak detection and facility risk reduction.

Task 4: Development and Harmonization of RCS

The Guidance Document was proposed to NFPA Review committee for inclusion into NFPA 2 next edition (Oct 2020); the outcome of the project has been regularly communicated to the international hydrogen safety community, including at the International Conference on Hydrogen Safety (2019, 2021) and HySafe Research Priority Workshop, 2020))

Publications and Presentations

Publications

- “Development of risk mitigation guidance for sensor placement inside mechanically ventilated enclosures – Phase 1,” A . B. Tchouvelev, W.J. Buttner, D. Melideo, D., Baraldi, B. Angers, Int. J. Hydrog. Energy 46(23):12439–12454, 2021, doi:10.1016/j.ijhydene.2020.09.108.
- Development of Risk Mitigation Guidance for Sensor Placement Indoors and Outdoors; Andrei V. Tchouvelev, William Buttner, Benjamin Angers, International Conference on Hydrogen Safety, Edinburgh Scotland (September 21-23, 2021) (submitted for review)

Presentations

- Sensors and monitoring, William Buttner et all, HySafe Research Priorities Workshop, Session Progress in Safety Research, Phenomena and Risk Control, October 29, 2020
- Guidance on Sensor Placement, proposed Technical Annex for NFPA 2 (undergoing ballot)