

William Buttner, Ph.D., Senior Scientist

Hydrogen Safety Research and Development program

Hydrogen Power, Production, and Storage Group

National Renewable Energy Laboratory

- Joined NREL in 2008 with over 25 years experience in gas sensors
- Led the development of the NREL Hydrogen Sensor Laboratory and served as its director since 2010
- Program Lead for the Hydrogen Safety Research and Development (HSR&D) Group
 - H₂ detection methodologies for safety and process monitoring
 - Component and system reliability and Risk Mitigation
 - Active in hydrogen codes and standards development
- Extensive number of publications and outreach on the development and use of gas detection methodologies with a focus on hydrogen for the past 15 years
 - Book: Sensors for Safety and Process Control in Hydrogen Technologies, T. Hubert, L. Brett, W. Buttner, CRC Press (2018)



UNIVERSITY OF
PITTSBURGH
INFRASTRUCTURE
SENSING

COLLABORATION WORKSHOP



The NREL Sensor Laboratory Hydrogen Leak Detection & Quantitation

William Buttner

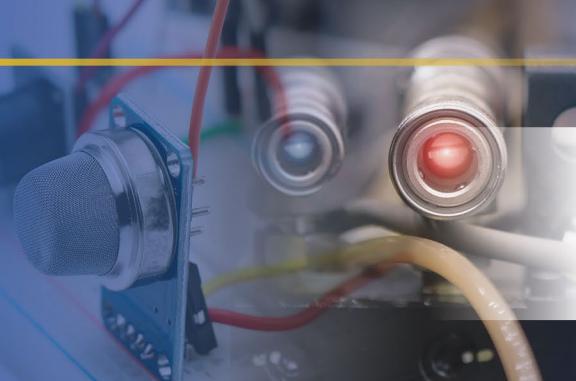
K. Hartmann, D. Peaslee, I. Palin, K. Lee, O. Robinson, J. Gifford

Hydrogen Safety Research and Development (HSR&D) Program

National Renewable Energy Laboratory

Golden, Colorado USA

November 8, 2023



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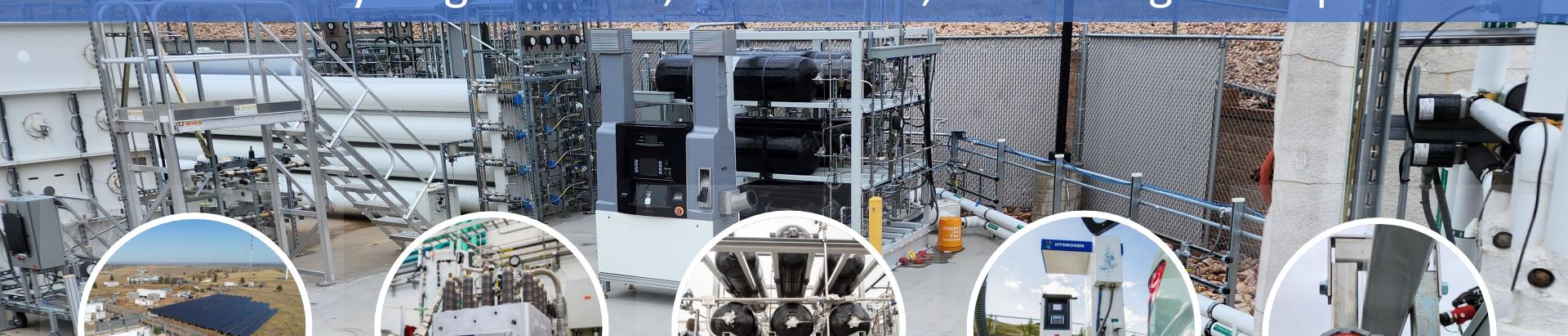
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Quick Overview of NREL's Hydrogen Infrastructure Research The Hydrogen Power, Production, and Storage Group



Grid and Renewables Coupling

Electrolyzers as dispatchable loads in power systems, dynamic operations and integration with renewable production

Hydrogen Production

Full stack scale electrolyzer and BOP performance, system optimization when coupled to grid/renewables and end uses

Distribution and Storage

System scale distribution and storage challenges, vehicle and ground storage performance and modeling

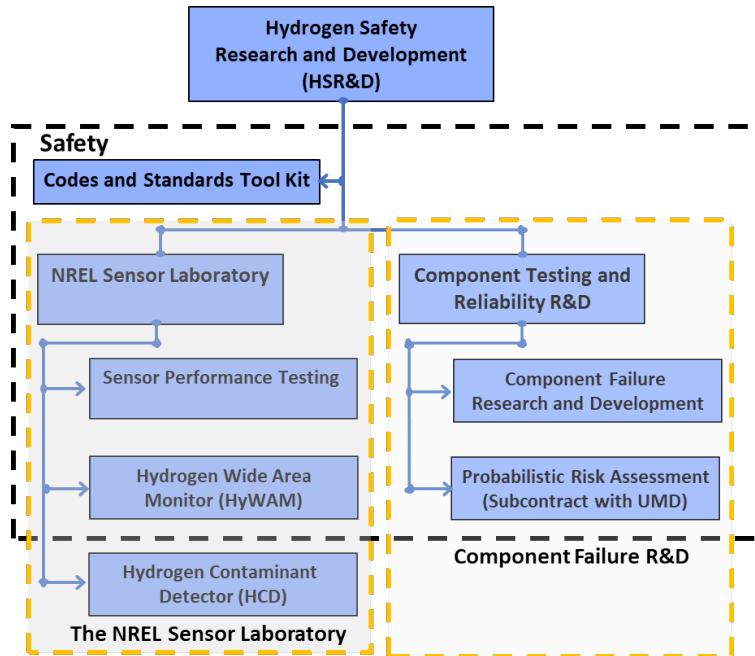
End Use Applications

Transportation applications, industrial applications, natural gas blending, renewable synthetic molecules

Safety and Sensors

Development and evaluation of safety and sensor systems, component failure characterization

Hydrogen Safety Research and Development (HSR&D) Organization (NREL Sensor Laboratory and Hydrogen Component Reliability)



HSR&D Organization

The NREL Sensor Laboratory

- Develop and validate detection methodologies for safety and process monitoring
- Topical studies on proper deployment of sensors
- Outreach and Stakeholder Engagement
 - CDOs & SDOs support
 - Formal and informal collaborations with stakeholders
 - Safety Working Groups (IEA, CHS, Mission Innovation, HySAFE)
 - Conferences and Workshops
- Focus areas to address growing and evolving H2 market

Component Failure R&D

- HyCReD (support QRA)
- Component and system leak rate quantification

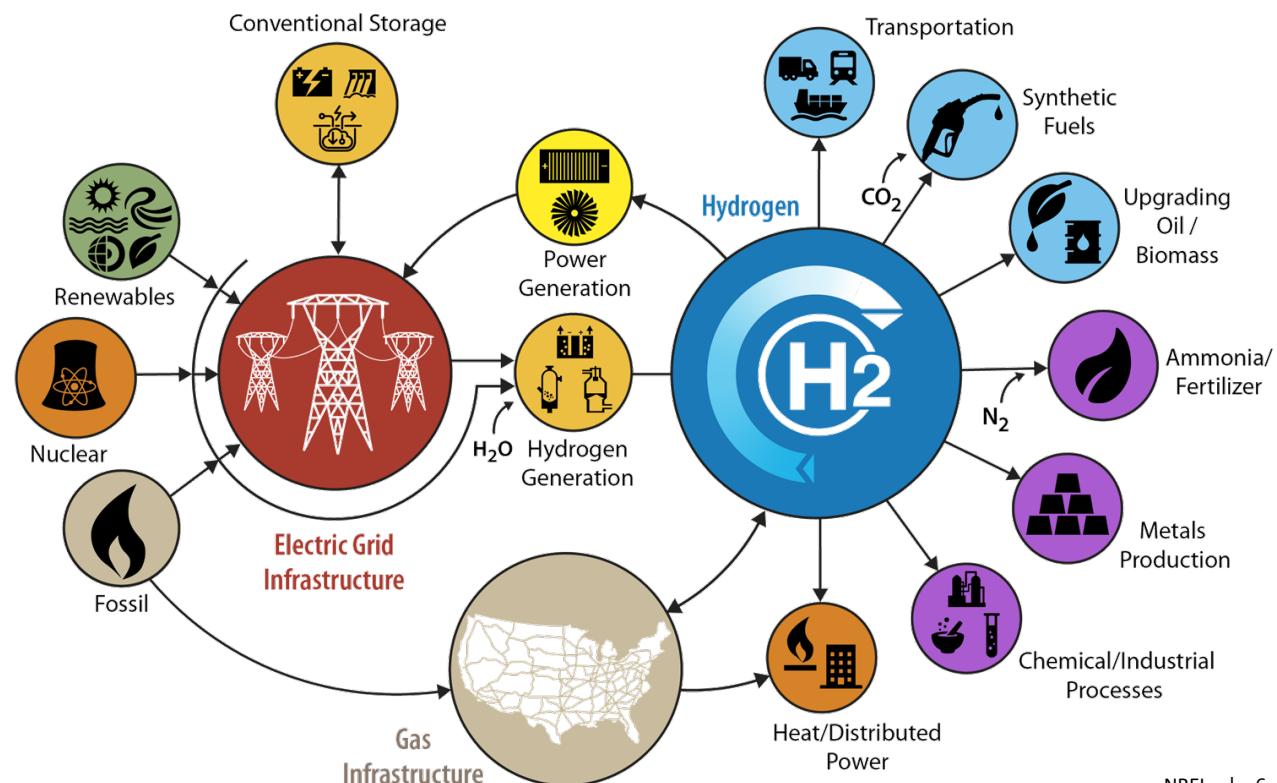
The NREL HSR&D Program is supported through the Analysis, Codes and Standards Subprogram of the DOE Hydrogen and Fuel Cell Technologies Office. The HSR&D program includes the NREL Sensor Laboratory.

Next Generation Detection Strategies for Hydrogen – for H2@Scale (and the Hydrogen Earth)

For large-scale applications, how will hydrogen sensor needs change?

What unique challenges might different applications present?

What are the H₂ Losses along the Value Chain?



See <https://www.energy.gov/eere/fuelcells/h2scale>

Reasons for Hydrogen Monitoring/Detection

Hydrogen Releases

- Safety
 - Avoid accumulation (and delayed ignition) (below the LFL of 4 vol% H₂)
 - Typical monitoring range of interest 0.1 to 10 vol% (1,000 to 10,000 ppm_v)
- Potential Environmental Concerns
 - Sub-ppm_v range of interest
- Maximize Product Throughput (market driven)
 - Identify losses along the value chain

Process Control Monitoring

- Fuel Quality / gas composition

From:

<https://electrek.co/2019/06/11/hydrogen-station-explosion-toyota-halts-sales-fuel-cell-cars/>



Detectors are a critical safety element in hydrogen facilities but can also support other critical functions

**Gas sensors/detectors are the most common strategy
for the direct detection and empirical characterization of hydrogen releases**

Current and Pending Research Topics for the NREL Sensor Laboratory

HFTO H2@Scale CRADA Call Supporting ARIES “Next Generation Hydrogen Leak Detection-Smart Distributed Monitoring for Unintended Hydrogen Releases” (focus on safety)

- NREL-led collaboration to develop “Next-Generation Sensor Technologies” for H2 releases based on Wide Area and Standoff methodologies for safety applications (with Ruishu Wright/NETL and private companies)
- Integrate detection technology with released empirically-validated hydrogen behavior modelling
- To supplement or supplant point sensors for safety monitoring of hydrogen releases.

DOE Funding Opportunity Announcement in Support of the Hydrogen Shot (focus on emissions monitoring and quantitation)

- Support development and deployment of sub-ppm hydrogen sensors

Support new markets and applications (focus detection & C&S support)

- Green Manufacturing, Hydrogen-Natural Gas blends, electric generation (turbines)
- Hydrogen Hubs
- Process Monitoring (H2 fuel quality, H2-NG applications)

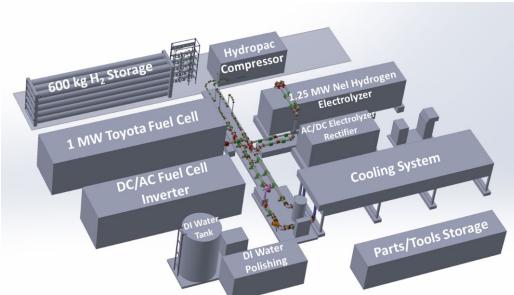
The NREL Sensor Laboratory supports the development and implementation of hydrogen detection methodologies in support of H2@Scale and the Hydrogen Shot

NREL Sensor Laboratory Resources and Capabilities

Sensor Performance Validation (Laboratory Capabilities) SSTA PGCA



Sensor Deployments/Demonstrations (ARIES facility) Vision (circa 2020) Reality (now)



Research Activity

- H₂ detector metrological assessment & deployments
- Sensor Guidance and Risk Mitigation
- Quantification of emissions and FQ

Laboratory Testing and Evaluation:

- Safety Sensor Test Apparatus (SSTA)
 - Updated for ppb_v detection limits
- Process Gas Characterization Apparatus (PGCA)
 - Operation of unlisted components in hazardous areas
 - Fuel Quality Testing (contaminants, H₂-NG Blends)

Deployments for Profiling and Modeling:

- Advanced Research on Integrated Energy Systems (ARIES)
 - NREL test bed for emission detection and quantification
 - CFD Modeling and validation of hydrogen releases
 - Green Manufacturing (new markets)
- Hydrogen Infrastructure Testing and Research Facility (HITRF)

Approaches for Standoff Detection and Hydrogen Wide Area Monitoring

Advanced Detection and Standoff Technologies

Hydrogen Wide Area Monitoring

Fiber Optic Sensing

Schlieren and Shadowgraph Imaging

Ultrasonic Leak Detection

Raman Sensing

Distributed remotely interrogated sensors

Flame Detection

Sub-ppm detection methodologies

System and Component Reliability

Modeling of released hydrogen behavior (CFD)



Photo by John Adams on Unsplash

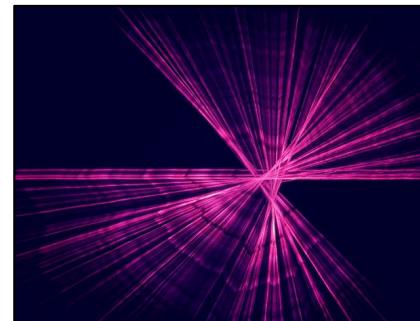


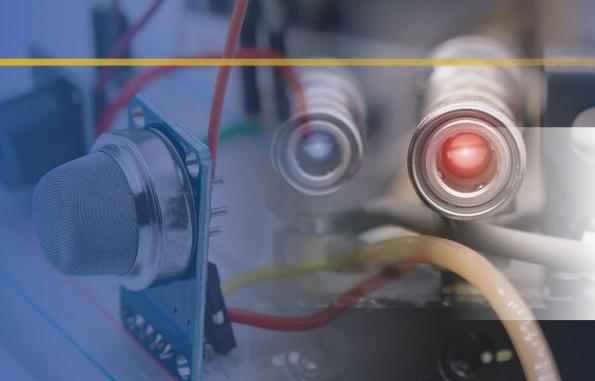
Photo by Erfan Afshari on Unsplash



Photo by Maximalfocus on Unsplash



Photo by David Laws on Unsplash



Summary

- Hydrogen detection facilitates the implementation of hydrogen infrastructure and markets as envisioned by H2@Scale and the Hydrogen Earth Shot by supporting:
 - Safety (rapid detection of unintended releases)
 - Emissions monitoring and quantitation to minimize product loss and potential environmental impact along the hydrogen value chain
 - Process Monitoring
- Point sensors will continue to play a role but have limitations, especially for large scale or outdoor applications.
- Stand-off and Wide Area Hydrogen Monitoring methodologies can supplement (and possibly supplant) point sensors for the detection of hydrogen releases for some applications.
- The NREL Sensor Laboratory will continue to support hydrogen deployment by the development and proper implementation of hydrogen sensors and advanced detection strategies to meet the needs of the hydrogen community.
 - Collaboration with the hydrogen stakeholders is encouraged.



NREL HITRF Station Expansion Under IHS Project

Thank You

www.nrel.gov

Contacts:

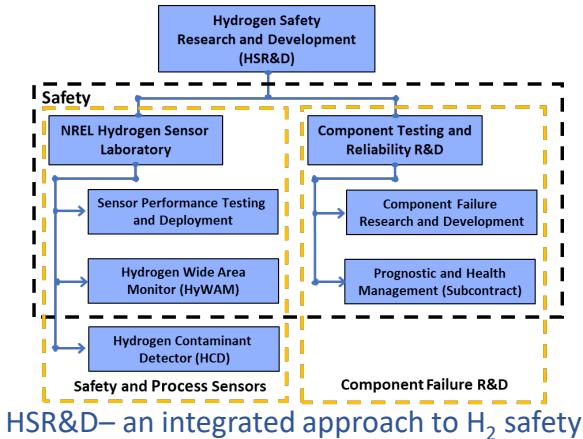
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Supplemental Information

The NREL Hydrogen Safety Research and Development (HSR&D) Program (within the Hydrogen Power, Production, and Storage Group)

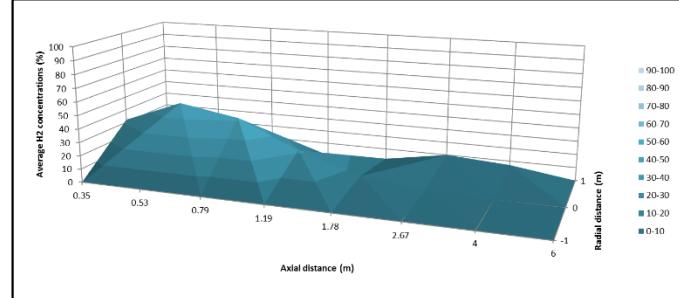


Testing apparatus and expertise for hydrogen safety and process sensors

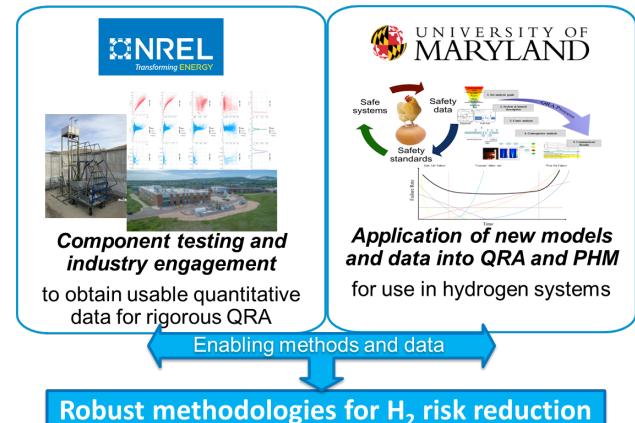
- The NREL Sensor Laboratory-experts in hydrogen detection and monitoring
 - Unique capability and resource
 - Safety and process control sensor testing and deployment studies
 - Advanced wide area / stand off detection technology for H2@Scale
 - Hydrogen release behavior modelling
 - Detection as a risk reduction strategy
 - Support sensor developers, end-users, and regulators
- Hydrogen Component Reliability R&D for probabilistic risk reduction QRA.
- Active membership on CDOs and SDOs (NFPA, ISO, UL, SAE, ASTM)
- National & International strategic partnerships to directly support stakeholders

Contact:

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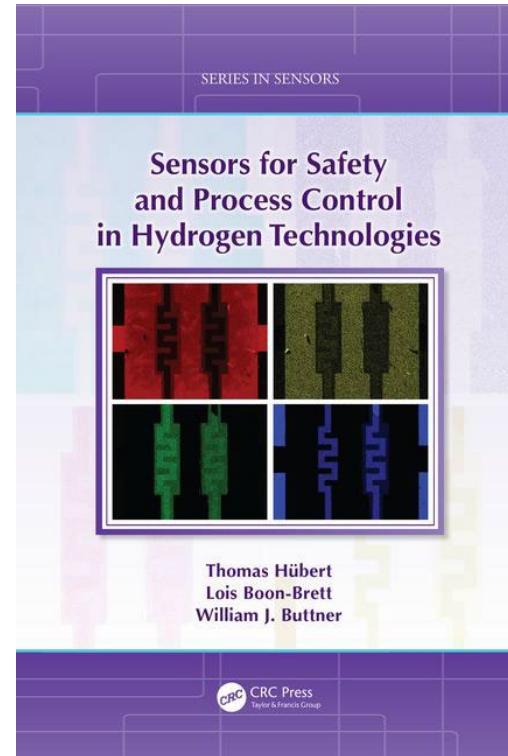
Hydrogen Wide Area Monitoring: H₂ release profiling using the NREL HyWAM



Hydrogen component R&D merges failures with probabilistic risk reduction (with UMD)

Highlights of the NREL Sensor Laboratory

- *(Book) Sensors for Safety and Process Control in Hydrogen Technologies* (co-Authored with sensor experts from JRC and BAM).
 - The NREL Sensor Laboratory now provides a unique resource to the hydrogen community
- Organized multiple Hydrogen Sensor Workshops
 - The NREL-DOE Hydrogen Sensor Workshop” Chicago, IL (June 8, 2011)
 - “Hydrogen Sensor Workshop—End-User Needs vs. Capability of Current Technology” Brussels, Belgium (May 10, 2017).
 - “Mission Innovation Clean Hydrogen Mission Workshop Hydrogen Detection Technologies for Safety -Maximizing opportunity for collaboration” Tokyo, Japan (March 17, 2023)
- *“An Overview of Hydrogen Sensor”*, IJHE, 2011; 36(3):2462-70 recognized as 5th most cited paper in IJHE (2011-2016)
- National and international collaborations and partnerships.
- 2018 DOE Hydrogen and Fuel Cells Program R&D Award (*For outstanding dedication and contributions to hydrogen safety, sensor technologies and the hydrogen refueling community*)



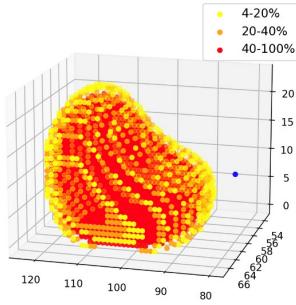
<http://www.crcnetbase.com/isbn/9781466596559>

Supplemental Information

HSR&D & NREL Sensor Laboratory R&D Outcomes

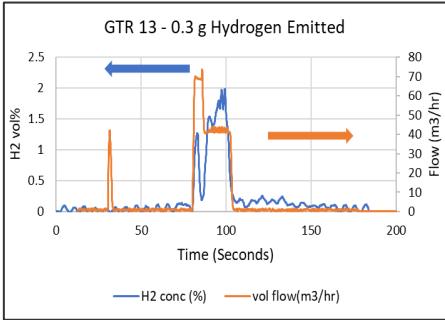
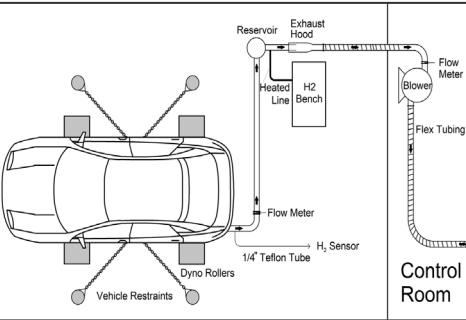
(Presentations from the International Conference on H₂ Safety, Sept 21)

NREL HyWAM Deployment at HSE (PRESLHY LH₂ Release study)



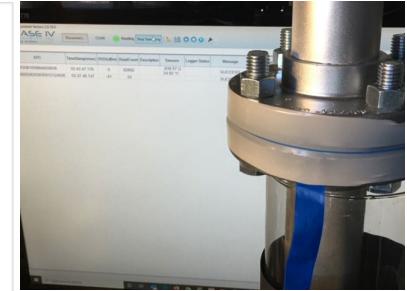
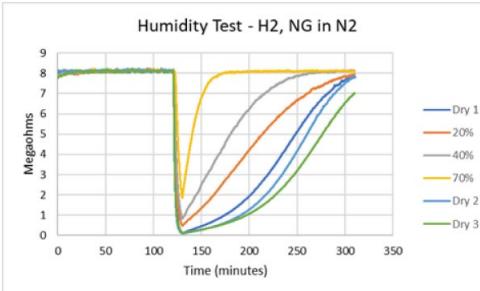
ICH斯 183: Visualization and Quantification of Wind-Induced Variability in H₂ Clouds Following Releases of Liquid Hydrogen, (I. Palin et al.)

FCEV H₂ Exhaust and Emissions Monitoring at ECCC and TC):



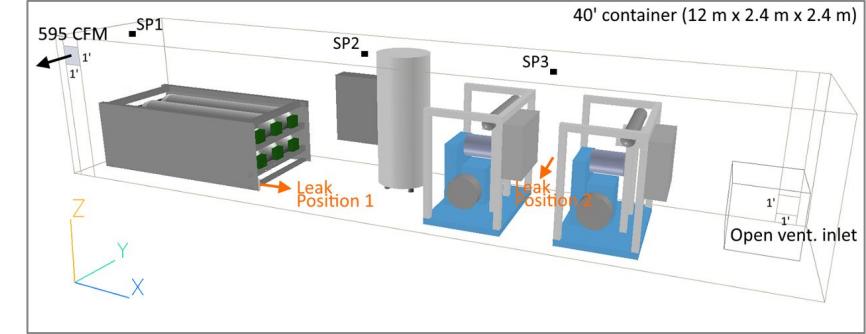
ICH斯 202: Fuel Cell Vehicle Hydrogen Emissions Testing, (D. Pearman et al.)

Support Sensor Development: selective H₂ detection in H₂-NG Blends (Element One)



ICH斯 285: Very Low-cost Wireless Hydrogen Leak Detection for Hydrogen infrastructure, (Hoagland et al.)

Component Reliability and Risk Mitigation (with UMD & AVT)



ICH斯 159: Hydrogen Equipment Enclosure Risk Reduction Through Earlier Detection of Component Failures, (Hartmann, et al.).

See also ICH斯 299 (IEA-H₂ Safety) and ICH斯 232 (HyCReD) with UMD