The NREL Sensor Laboratory

Hydrogen Leak Detection for Large Scale Deployments

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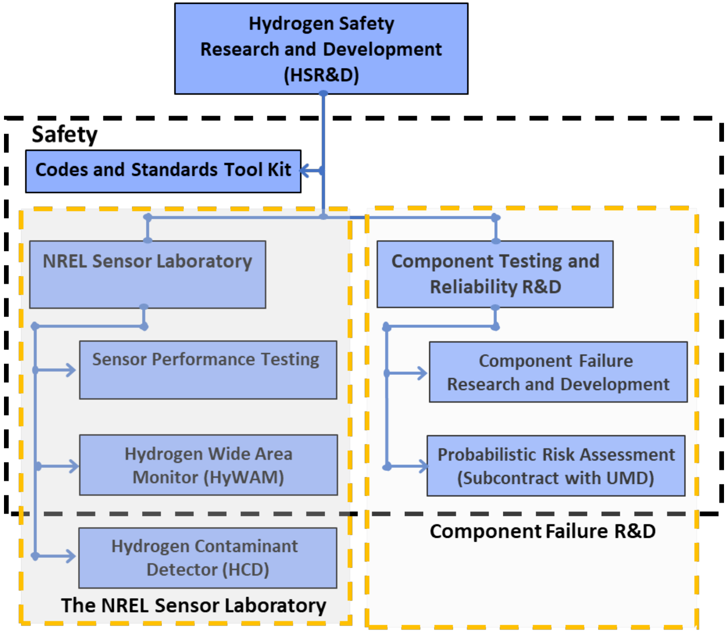
Hydrogen Safety Research and Development (HSR&D) Organization (NREL Sensor Laboratory and Hydrogen Component Reliability)



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
  - Conferences and Workshops
- Focus areas to address growing and evolving H2 market

Component Failure R&D (with UMD)

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

The NREL HSR&D Program includes the NREL Sensor Laboratory, which was established to assure that stakeholders have the hydrogen detection technology they need.

Reasons for Hydrogen Monitoring/Detection

Hydrogen Releases

- Safety
  - o Avoid accumulation (below the of LFL of 4 vol% H_2)
  - o Typical monitoring range of interest 0.1 to 10 vol% (1,000 to 10,000 ppm_v)
- Potential Environmental Concerns
  - o Sub-ppm_v range of interest
- Maximize Product Throughput (market driven)
  - o Identify losses along the value chain

Process Control Monitoring

- Fuel Quality / gas composition

From: https://electrek.co/2019/06/11/hydrogen-station-explodes-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

Overview of Hydrogen Releases along the value chain

Operational Hydrogen Releases

- Depressurization events (LH2 Tanks, fueling events)

Design Features

- Permeation through vessel walls, seals (usually small)

Unintended Releases (Leaks/out of normal events)

- Safety Venting (e.g., PRD activation)
- Breaches / component failure
- Size considerations
  Small leaks ("inconsequential" amounts)
  Larger Leaks (potential safety concerns)

Different sources contribute to the total H2 emissions from across the value chain.

LH2 Venting following delivery

Small leak identified by a soap solution

NREL Sensor Laboratory Resources and Capabilities

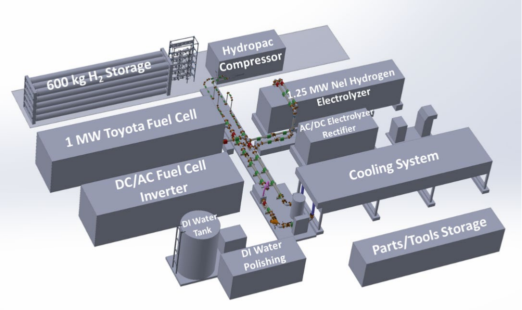
Sensor Performance Validation (Laboratory Capabilities)

SSTA

PGCA

Sensor Deployments/Demonstrations (ARIES facility)

Vision (circa 2020)



Reality (now)

Research Activity

- Metrological Assessment & Deployments
- Sensor Guidance and Risk Mitigation
- Quantification of emissions and FQ

Laboratory Testing and Evaluation:

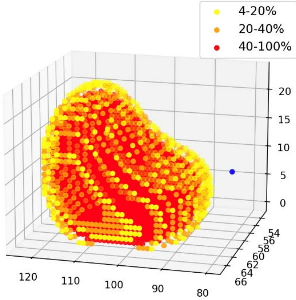
- Safety Sensor Test Apparatus (SSTA)
  - Updated for ppb_v detection limits
- Process Gas Characterization Apparatus (PGCA)
  - Operation of unlisted components in hazardous areas
  - Fuel Quality Testing (contaminants, H2-NG Blends)

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 (pending)
- Hydrogen Infrastructure Testing and Research Facility (HITRF)

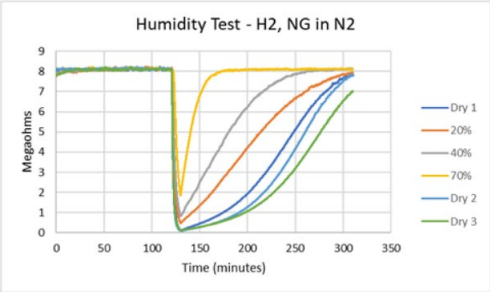
HSR&D & NREL Sensor Laboratory R&D Outcomes

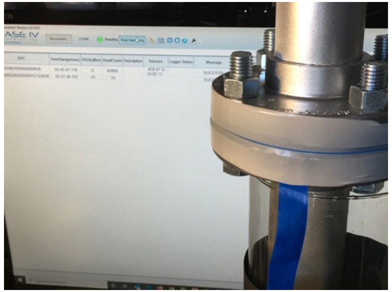
NREL HyWAM Deployment at HSE (PRESLHY LH2 Release study)



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

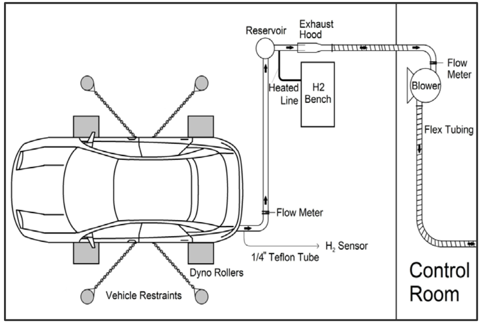
Support Sensor Development: selective H2 detection in H2-NG Blends (Element One)

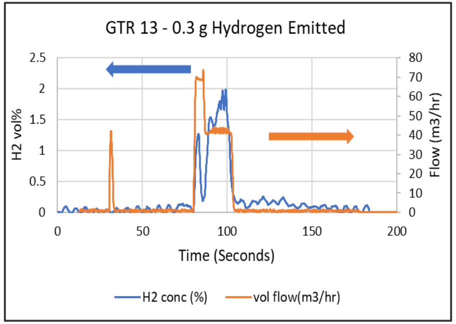




ICHS 285: *Very Low-cost Wireless Hydrogen Leak Detection for Hydrogen infrastructure,* (Hoagland et al.)

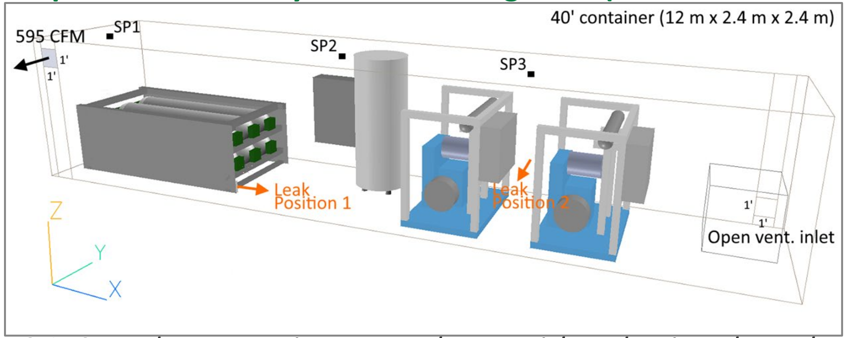
FCEV H2 Exhaust and Emissions Monitoring at ECCC and TC):





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

Component Reliability and Risk Mitigation (with UMD & AVT)



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

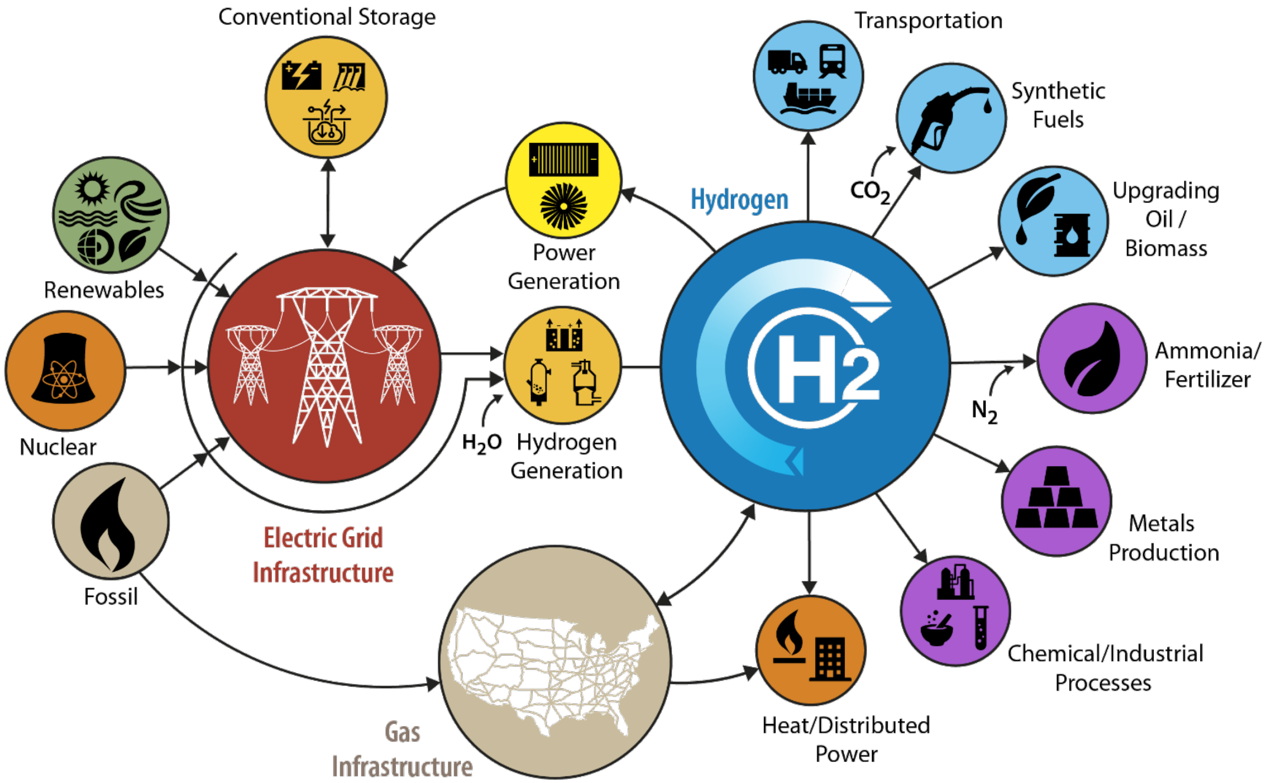
See also ICHS 299 (IEA-H2 Safety) and ICHS 232 (HyCReD) with UMD

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 H_2 Losses along the Value Chain?



Advanced Detection Technology R&D
(Current and Pending Research Topics)

HFTO H2@Scale CRADA Call Supporting ARIES

- "Next Generation Hydrogen Leak Detection--Smart Distributed Monitoring for Unintended Hydrogen Releases"
  - NREL-led collaboration to develop "Next-Generation Sensor Technologies" for H2 releases based on Wide Area and Standoff methodologies for safety applications
  - Integrate detection technology with released empirically-validated hydrogen behavior modelling
  - To supplement or supplant point sensors for safety monitoring of hydrogen releases.

Hydrogen Shot and a University Research Consortium on Grid Resilience (DOE FOA)

- Industry/university-led R&D to develop gas detection technology for ppb_v detection capability to support emissions monitoring and quantitation in outdoor application.
- NREL Sensor Laboratory to support development and demonstration of 5 emerging sensor technologies for ppb_v range detection (pending)

Support new markets and applications (pending)

- Support of Green Manufacturing, Hydrogen-Natural Gas blends, electric generation (turbines)

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

Photo by Maximalfocus on Unsplash

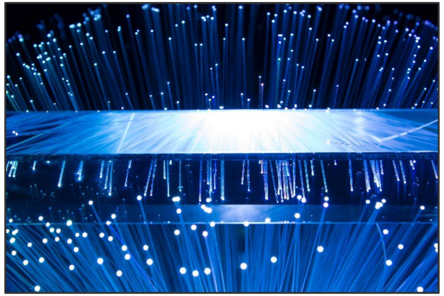


Photo by John Adams on Unsplash

Photo by David Laws on Unsplash

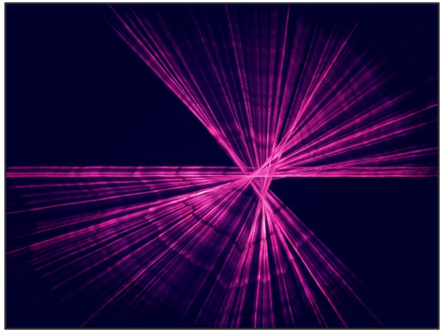


Photo by Erfan Afshari on Unsplash

Ultrasonic Leak Detection

Ultrasonic Leak Detection

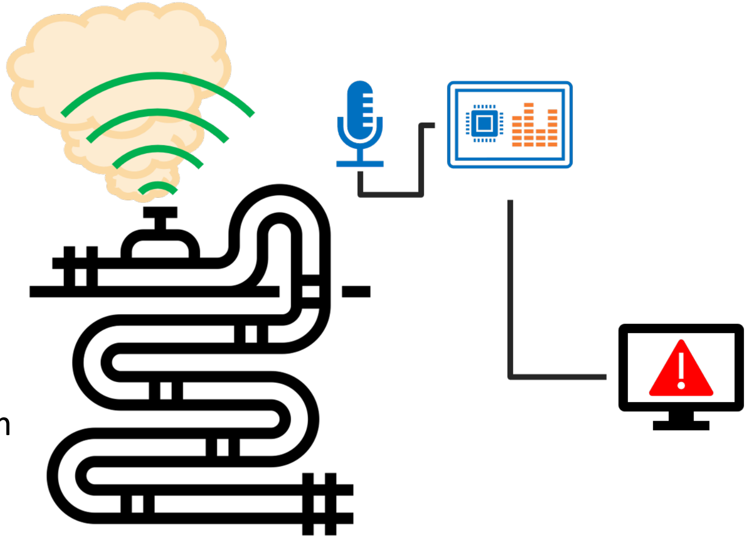
- Ultrasonic Detection (25-100 kHz range - microphone, piezo)
  - Acoustic response in response to a pressurized gas escape
  - Sound profile for the local background noise is recorded
  - Changes in sound parameters indicating a leak
  - Commercially available but limited use in H_2 facilities (so far). On-going NREL evaluating commercial units in HITRF & LOD (Project Partners include Shell and Emerson Instruments)

Technology Benefits

- Detection does not depend on gas accumulation
- Single device can monitor large areas (claimed radius of detection from 5-20 m depending on ambient conditions and the size of a leak)
- Fast, remote, non-contact detection of gas releases

Technology Challenges/Limitations

- Dissipates quickly with distance affecting making detection of small leaks difficult
- Operational ultrasound sources during normal (non-leaking) operation
- Current technology does not indicate the location of the leak



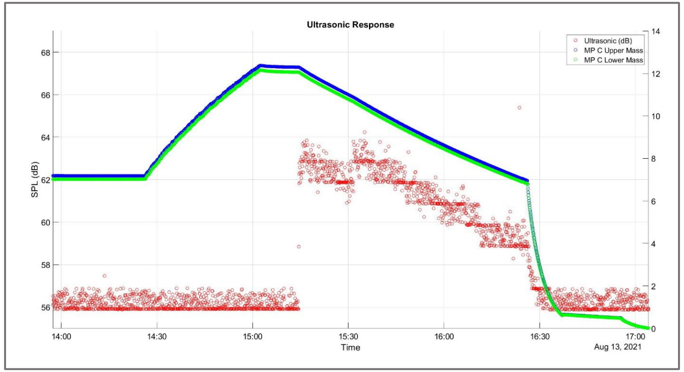
Principle of Ultrasonic Leak Detection

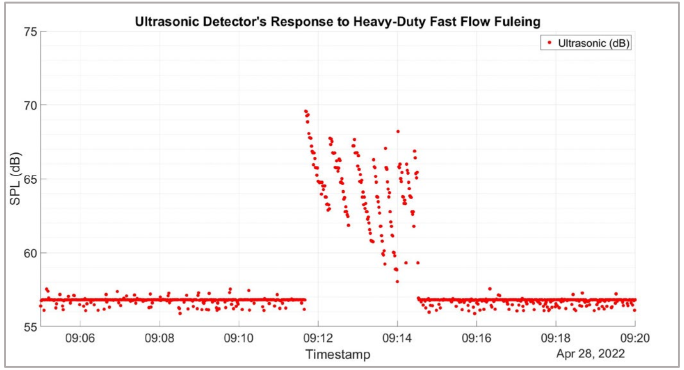
Commercially available, not demonstrated extensively for hydrogen

Ultrasonic Leak Detection at HITRF

Fitting failure on a medium pressure hydrogen tank

- Response from ULD (~64 dB); alarm SP at 70 dB
- Pressure drop from ~5800 psi to 2900 psi (manually initiated by-pass depressurization to vent)
- Demonstration at commercial facility is pending





Operational Interferences
Response of the ultrasonic detector to a heavy-duty fast flow fueling

Fiber Optic Sensing

Fiber Optic Sensing

- Configured with sensing elements along length or at tip
- Detectors can determine the location of the stimuli along the cable (Temperature, Strain, Acoustics, Gas Composition)
  - Hydrogen selective sensors less common
- Allows for distributed remote detection of target stimuli

Technology Benefits

- Distributed point detection for difficult to access areas
  - Fiber optic cable is not an ignition source
  - Pipeline and down borehole monitoring (H2 storage & transport)

Technology Challenges

- Hydrogen Specific Fiber Optic Systems
  - Degradation by poisoning or delamination of the sensitive layers
  - Long-term stability
- Lack of (validate) hydrogen specific sensors
- Cost and deployment challenges

Fiber Optic Installation along a pipeline
Photo Courtesy of Paulsson Inc (PI)

Commercially available, not demonstrated extensively for hydrogen

Schlieren and Shadowgraph Imaging

Schlieren and Shadowgraph Imaging

- Difference in refractive index in non-homogenous media (i.e. density)
    - Temperature, Pressure, Gas Composition, Shock Waves
- Allows for remote detection and location of target stimuli

Technology Benefits

- Commercialized for some applications (e.g., imaging for burner ventilation)
- Hydrogen specific detection has been demonstrated in laboratory settings

Technology Challenges

- Generally qualitative not quantitative – visual indicator
- Processing time may be required
- Focal depth
- Impacted by variable environmental conditions could affect the accuracy (Heat Radiance, Rain, Lighting, Dust)

Example of Schlieren observed at a hydrogen vent at NREL.

Limited commercial availability; needs R&D for hydrogen

Flame Detectors

Flame Detectors

- A hydrogen flame is nearly invisible in daylight
- Burning hydrogen has low radiant heat emission
- A flame monitor will remotely measure infrared (IR) light that is emitted by burning flammable gases

Technology Benefits

- Will cover large areas and monitor for dangerous conditions
- Able to detect hydrogen specific infrared bands
- Can be connected to automatic shutoff and source isolation

Technology Challenges

- Improperly selected detectors may not reliably respond
- Line of sight limitation
- Field calibration and validation methods
- Challenges due to false positive alarms:
  - Background Light or Reflected Sunlight
  - Limited information on False Negatives

Photo by Dennis Schroeder, NREL 40082

Flame monitor installed at the NREL hydrogen dispenser

Extensive commercial usage; needs R&D for acceptance in hydrogen applications

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

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