

# NREL Hydrogen Sensor Testing Laboratory

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National Renewable Energy Laboratory

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\*Interns from <sup>1</sup>Colorado School of Mines and <sup>2</sup>UC Boulder

DOE Hydrogen Program  
2024 Annual Merit Review and Peer Evaluation Meeting

Project ID: SCS021

# Project Goal

## Hydrogen Sensor Testing Laboratory

The NREL Sensor Laboratory supports HFTO's mission for the safe and efficient implementation of hydrogen as an energy carrier:

- Facilitate the development and use of hydrogen detection technology for safety, process control, and emissions quantification and mitigation.
- Support hydrogen codes and standards development and safety research.
- Support development of advanced hydrogen detection methodologies for early leak detection.
- Provide stakeholders with an unbiased and unique resource to validate sensor performance to application requirements.

The NREL Sensor Testing Laboratory was established to assure that stakeholders have the hydrogen detection technology they need.

# Overview

## Timeline and Budget

- Project start date: 10/01/2010
- FY23 DOE funding: \$925,000
- FY24 planned DOE funding: \$900,000
- Total DOE funds received to date\*: \$6,800,000
  - \* Since the project started

## Barriers

- Hydrogen Safety Codes and Standards
  - 3.7.5.G – Insufficient Technical Data to Revise Standards
  - 3.7.5.H – Insufficient Synchronization of National Codes and Standards
  - 3.7.5.J – Limited Participation of Business in the Code Development Process

## Partners

- Project lead (PI): Dr. William Buttner, NREL
- Co-PI(s): D. Peaslee, J. Stewart, L. Martens, G. Saur.
- Partner organizations
  - AVT and Associates, Sensor Placement R&D (AOP subcontract)
  - University of Maryland, Component Reliability
  - SNL (HyWAM and HySCAN)
  - PNNL (HySCAN)
  - LANL (Fuel Quality Sensor)
  - SPPs: Shell, CARB, Element One, Amphenol
  - HFTO CRADA in Support of H2@SCALE: GTI, EPRI, Paulsson, Element One, Renewable Innovation, Boyd Hydrogen
  - Hydrogen Shot FOA: UGA, ISU, MU, GE Research, Indrio

# Potential Impact

## Role of Hydrogen Sensors/Detection

### Potential Negative Impacts of Released H<sub>2</sub>

- Potential for fire or worse; early detection minimizes impacts.
- Hydrogen releases can lead to facility downtime, product loss, and potential environmental impacts

*Hydrogen sensors are the most common way to detect and mitigate hydrogen releases. Detection can provide risk mitigation credits*

### Process Control

- Monitor for fuel impurities or constituents (e.g., FQ, H<sub>2</sub>-natural gas blends)
- Prevent system damage

*Identify out-of-compliance fuels before use (by FCEVs)*

From:

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



Hydrogen Sensors are a critical element for facility safety and to optimize operational efficiency but must be reliable and properly deployed to be effective.

# Approach

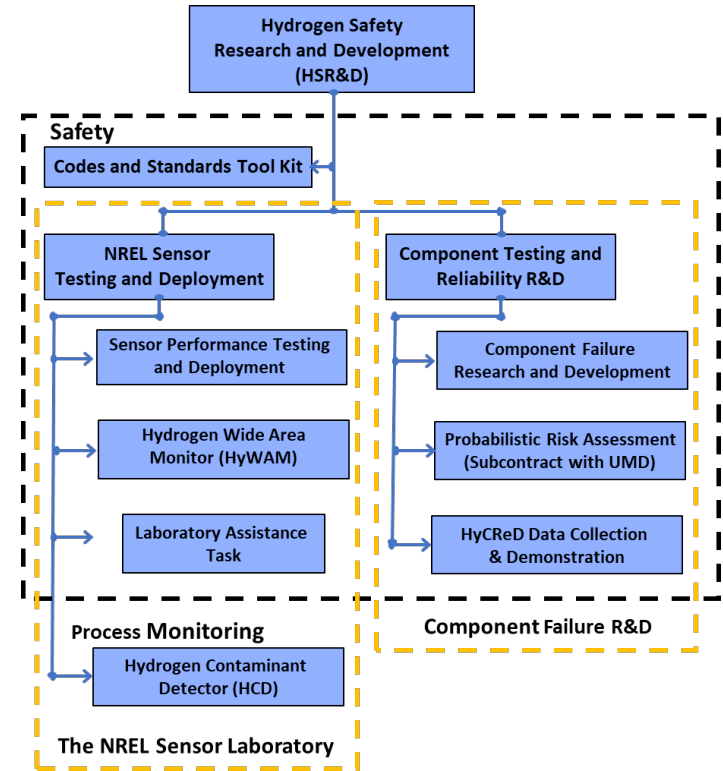
## The NREL Sensor Laboratory

### NREL HSR&D Program

- The NREL Sensor Laboratory
  - Methodology for detection of H<sub>2</sub> releases
  - Advanced detection methods
  - Support modelling of hydrogen behavior
  - Process monitoring
- Component Testing and Reliability
  - Frequency and consequences
- Support of hydrogen codes and standards

*Detection and Mitigation of the Impacts  
of Unintentional Hydrogen Releases  
for Safety and Reliability*

The NREL Sensor Testing Laboratory is part of a multi-faceted program supporting hydrogen facility safety and reliability and outreach to stakeholders





# Approach

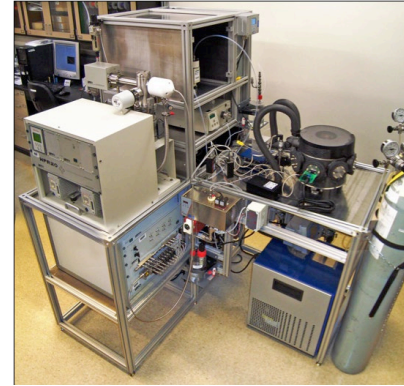
## The NREL Sensor Laboratory

### Unique Sensor Testing and Deployment Capability

- Safety Sensor Test Apparatus (SSTA) and other laboratory fixtures
  - Metrological performance assessment of hydrogen sensors
  - Topical studies / custom applications
  - Emerging technologies and markets in support of H2@Scale
- Process Sensors and Process Control Applications (Process Gas Characterization Apparatus, PGCA)
  - NEC-compliant for testing non-listed devices in 100% H<sub>2</sub>
- Access to the Advanced Research on Integrated Energy Systems (ARIES) facility
  - Test bed for sensor demonstrations and release studies

### Outreach

- Direct collaboration with stakeholders
- CDOs/SDOs, Safety Groups (Center for Hydrogen Safety)
- Conferences and Workshops



The SSTA  
Laboratory sensor test  
apparatus for safety and  
emissions sensor testing.



The ARIES facility  
Large scale H<sub>2</sub>  
production and power  
generation; available for  
H<sub>2</sub> release studies  
(commissioned in  
January 2024).

The NREL Sensor Laboratory provides a unique capability to the hydrogen community not otherwise available

# Approach: Safety Planning and Culture

(HSP not required)

## Organizational

*“Hazards Are Identified and Evaluated for Every Task, Every Time”*

*-NREL Environment, Safety, Health, & Quality Safety Culture*

- NREL research plans are reviewed by subject matter experts (SME) and ESH officers.
- Comprehensive hazard analyses for design and operations (pressure, safety, chemical safety) and reviewed with team (managers to technicians).
- Workers are verified to have completed extensive safety training

## The NREL Sensor Program

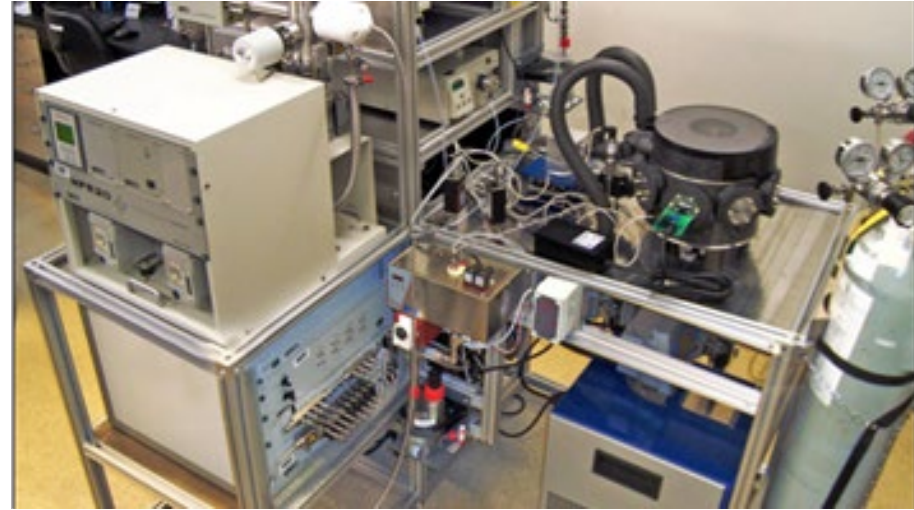
*The NREL Sensor Laboratory mission is to support the safe implementation of hydrogen. Recent activities include:*

- Hydrogen Safety Working Groups white papers
  - Mission Innovation Off Road Working Group Report *Hydrogen Detection Development and Demonstration*
  - CHS Working Group on H2-NG blends Best Practices (
- Nick Bartlett, NREL Fire Marshal.
  - Co-organized “First Responder Training” given by Nick Barilo to NREL staff and first responders in our surrounding community
  - Quarterly discussions on the use of sensors within NREL Resources.
- Support HUBs and large-scale projects to guide safe designs and operations and address community concerns (pending projects).

# Accomplishments and Progress: Responding to emerging applications

The NREL Safety Sensor Testing Apparatus (SSTA) was developed to evaluate H<sub>2</sub> safety sensors.

- Upgraded for verifying H<sub>2</sub> sensors down to 15 ppb<sub>v</sub>. Low H<sub>2</sub> levels in test gas verified with Peak Laboratories Analyzer
  - Applicable for SSTA and outdoor ARIES deployments
  - Supports emerging applications (including sensors developed under *the Hydrogen Shot* FOA)



*The NREL Safety Sensor Testing Apparatus (SSTA)*



**Peak Performer 1  
RCP (Reducing  
Compound  
Photometer)- H<sub>2</sub>,  
CO in Air (910-105)**

The Sensor Laboratory has testing capability to validate hydrogen sensors with sub-ppm<sub>v</sub> detection limits. This provides tools to validate H<sub>2</sub> behavior models and to quantify hydrogen releases within a facility.

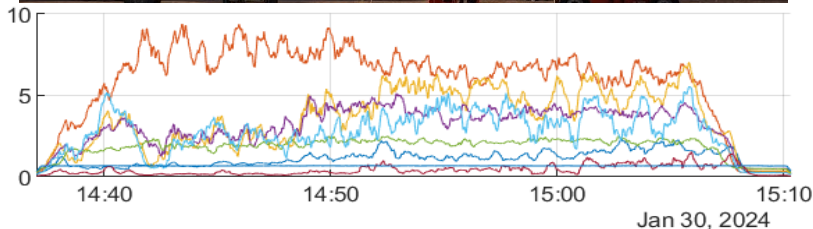


# Accomplishments and Progress

The NREL HyWAM supports elucidation of LH2 releases

Hydrogen Wide Area Monitoring: The quantitative or qualitative 3-dimensional spatial and temporal profiling of planned or unintentional hydrogen releases

## The SNL Thunder Tube LH2 Release study



## NREL HyWAM SNL Deployment

- SNL-led study on released LH2 within an enclosed test facility to refine behavior models to inform safety codes and standards
- The NREL HyWAM was used to profile H<sub>2</sub> levels downstream from release point
  - Provide data on H<sub>2</sub> dispersion
  - Support experiment safety
  - Data can be used to better understand leaks and uncontrolled releases for the improvement of H<sub>2</sub> safety

**The NREL HyWAM supports profiling of hydrogen releases and model development.**

# Accomplishments and Progress Hydrogen Contaminant Detector (HCD)

## Objectives:

- Develop a methodology for on-site, near-real time verification of fuel quality as per SAE J2719 (and ISO 14687) within NREL
- Provide a test bed for new HCD analyzers for in-line use
- Integrate in-line hydrogen contaminant detectors into commercial fueling dispensers for both LD and HD fueling infrastructure

## Recent Accomplishments:

- Completed the integration of a multi-analyte HCD into the NREL dispenser for in-line FQ verification.
  - Performed analysis on dispensing fuel (no target impurities were present at detectable levels).
  - Completed market analysis for water analyzer and completed down-selection. Laboratory evaluations are on-going.
  - Member of organizing committee for a proposed ASTM D03 Workshop on H<sub>2</sub> FQ verification methods.



Integration of an HCD at the NREL Dispenser  
The HCD enclosure regulates environmental parameters for HCD operation and is positioned outside the electrically classified area to facilitate deployment.

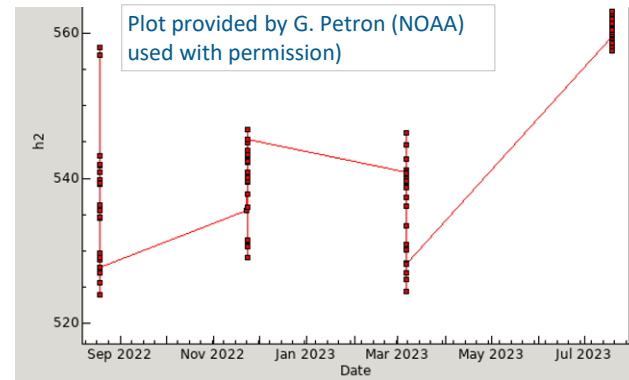
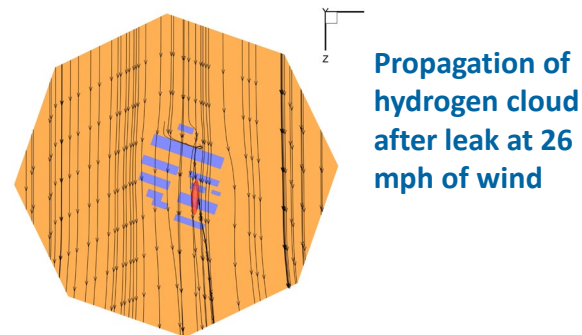
On-site fuel quality verification minimizes the likelihood of dispensing out-of-specification H<sub>2</sub>, which can severely damage FCEVs.

# Accomplishments and Progress

## ARIES: Testbed for Released Hydrogen Detection and Quantitation

### Hydrogen Emissions Monitoring and Quantification

- H<sub>2</sub> releases have potential adverse impacts
- Established ARIES as a test site for outdoor sensor demonstrations and model development of released hydrogen behavior
  - Support validation of sensors, including those developed under the Hydrogen Shot FOA
  - Developed CFD model for H<sub>2</sub> releases at ARIES
    - Guide sensor placement for improved detection and quantitation of releases
  - On-going partnership with NOAA to measure ambient H<sub>2</sub> levels
    - To quantify increased ambient levels of H<sub>2</sub> due to proximal activity
    - To support validation of the NREL-developed CFD dispersion model for H<sub>2</sub> venting at ARIES



ARIES: An NREL testbed to develop, validate, and deploy detection methodologies for facility safety and to quantify releases along the H<sub>2</sub> value chain.

# DEIA/Community Benefits Plans and Activities

## Commitment to Diversity and Economic/Environmental Justice

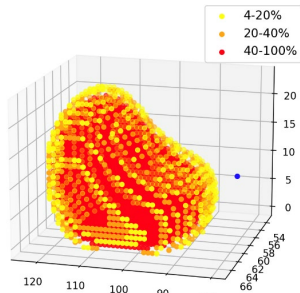
- Connected with NREL contact for the Faculty-Applied Clean Energy Sciences (FACES) Program aimed at course material development for minority supporting universities
  - One professor identified whose research interests overlap work - hydrogen infrastructure impacts to surrounding communities and hydrogen leakage in pipelines
- Working on hosting 2 women graduate researchers at NREL to support their graduate research
  - Educating next generation of researchers and engineers in hydrogen
- Support of John Hopkin's [SARE](#) program for under-privileged youth (coordinated by Olivia Robinson).
- Supporting the development of safety and monitoring plans for several pending large-scale hydrogen projects that include outreach to support hydrogen as a clean and safe fuel to community stakeholders.



# Accomplishments

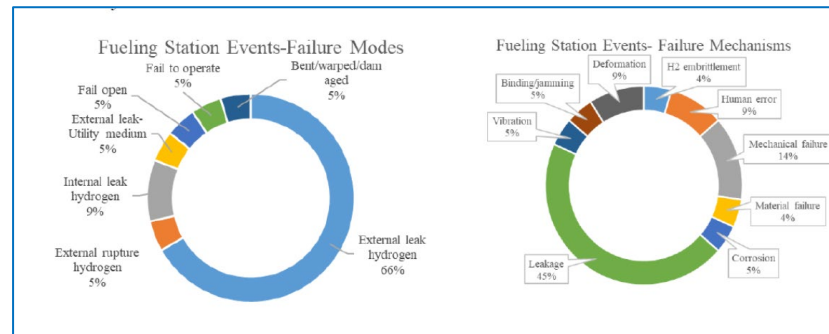
(presentations at the 2023 International Conference on Hydrogen Safety)

## NREL HyWAM Deployment at HSE (PRESLHY LH2 Release study)



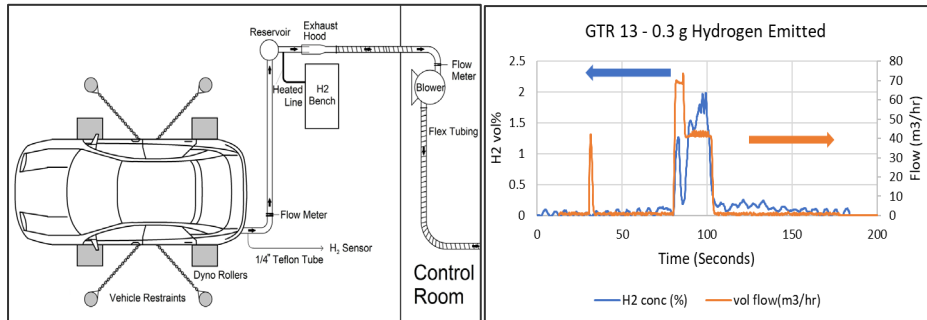
Visualization and Quantification of Wind-Induced Variability in H<sub>2</sub> Clouds Following Releases of Liquid Hydrogen, I. Palin et al.

## UMD- NREL HSR&D Collaboration on Component Reliability



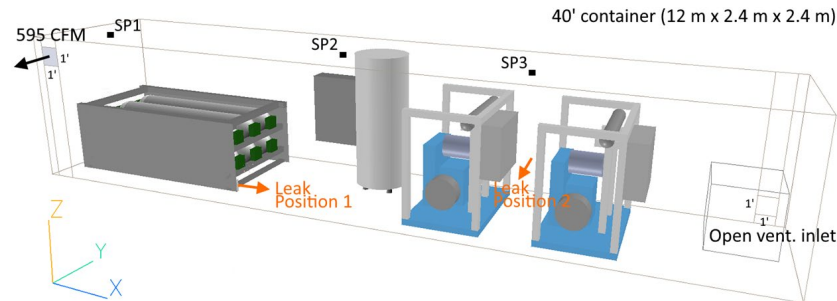
Populating the Hydrogen Component Reliability Database (HyCReD) with Incident Data from Hydrogen Dispensing, Ahmad Al-Douri et al.

## FCEV H<sub>2</sub> Exhaust Monitoring and Quantitation at ECC and TC:



Fuel Cell Vehicle Hydrogen Emissions Testing, D. Pearman et al.

## HEE Risk Mitigation via earlier detection (with UMD & AVT)



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



# Accomplishments and Progress

## Advanced Detection Methodologies for H<sub>2</sub> Releases

NREL Sensor Laboratory-Led CRADA in support of H<sub>2</sub>@SCALE

*Next Generation Hydrogen Leak Detection--Smart Distributed Monitoring for Unintended H<sub>2</sub> Releases*

(Partners: NETL, GTI, EPRI, Paulsson, Inc. Renewable Innovation, Boyd Hydrogen, Element One)

- To implement wide area and standoff hydrogen leak detection for facility safety with NREL HyWAM as the “reference” technology
- To develop CFD models to guide detector placement, identify leak source location, and quantify releases.

See **Poster SCS 032**: *Smart Hydrogen Wide Area Monitoring for Outdoor H<sub>2</sub>@Scale Demonstration Sites and Enclosures*; Dave Peaslee (NREL) et al.

NREL Sensor Laboratory supporting development of Sensors for ppb<sub>v</sub> H<sub>2</sub>

FOA in Support of the Hydrogen Shot

- University- or Industry-led projects to develop H<sub>2</sub> sensors for the “*Development and Validation of Sensor Technology for Monitoring and Measuring H<sub>2</sub> Losses*”; NREL to provide sensor performance validation and deployment expertise.

**Poster SCS036**: *The Electrical Hydrogen Sensor Technology with a Sub-minute Response Time and a Part-per-Billion Detection Limit for Hydrogen Environmental Monitoring*; Tho Nguyen, UGA

**Poster SCS038**: *Real-time Ionic Liquid Electrochemical Sensor for Highly Sensitive and Selective hydrogen Detection and Quantification*; Xiangqun Zeng; University of Missouri

**Talk SCS037**: Sensing Hydrogen Losses at 1 ppb-Level for Hydrogen-Blending Natural Gas Pipelines, Shan Hu, ISU

# Accomplishments and Progress (Internships within the NREL Sensor Laboratory)

## Continued mentoring of college interns within the NREL Sensor Laboratory

- Mutually beneficial; Real-world research experience in H<sub>2</sub> and alternative energy R&D
- Assigned as “technical lead”
  - Interactions with clients
  - Good publication record
- Current interns:
  - Ian Palin, Mines (Sensor Testing Support and Analysis)
  - Olivia Robinson UC Boulder, (Component Reliability and DEIA)
  - (Pending) 2 Graduate Student Internships for their university research R&D.
- Successful careers
  - Several have been hired on at NREL (FTE & Consultants)
  - Members and former members of the HSR&D Team started as interns within the NREL Sensor Laboratory



An NREL Internship provides real world experience in renewable energy.  
Several Sensor Laboratory Interns have been hired by NREL.

# Accomplishments and Progress: Response to Previous Year Reviewers' Comments

## **Project Strengths (direct extractions from the 2023 review):**

- The hydrogen sensor laboratory is clearly a much-needed resource for DOE and industry and should be expanded and supported to address even more topics. All project accomplishments listed for this year are well delivered and demonstrate the high caliber of the facility and experts there.
- The project is concentrating on the overall safety and economic drivers for sensor development and improvement. Improving the safe implementation of all hydrogen systems is nothing but positive.
- The project addresses key aspects of hydrogen detection and risk mitigation. Learnings are shared with codes and standards development organizations.
- This project is clearly the best on the planet and is a real gem for the global hydrogen community. The team is encouraged to keep it up.

## **Reply:**

I cannot add to these observations. The NREL team will continue to strive to maintain this level of research excellence.

## **Project Recommendations:**

The project should consider onboard “vehicle” hydrogen detection technology, especially in light of the expanded end uses for FCEVs, including Class 8 trucks, rail, marine, and aviation. Following are some topics for future consideration:.

## **Reply:**

The NREL Sensor Laboratory has supported HD applications, and this support is growing. Current and Pending industrial partnerships have been established to support HD Vehicle infrastructure for Road Vehicles and for rail applications. The NREL Sensor Laboratory supported the Missions Innovation Off-Road Working Group (Safety Task Team) on the development of the report “Hydrogen Detection, Development and Demonstration” which covered both on-board vehicle and infrastructure applications.

The NREL Sensor Laboratory reviews for 2023 recognized the importance and contribution of the NREL Sensor Laboratory to Hydrogen Safety .

# Collaboration and Coordination

## HyWAM Deployment/H<sub>2</sub> Releases

- Health and Safety Executive
- Sandia National Laboratory

## Sensor Testing and Deployment

- Environment and Climate Change Canada
- Transport Canada
- Shell Hydrogen (TSA)
- Amphenol (TSA)
- Element One (FIA)
- H<sub>2</sub> Earthshot (FOA DE-FOA-00002792); ppbv H<sub>2</sub> Sensors
  - UGA, ISU, UM, GE Research, Indrio

## Fuel Quality Analysis and Applications

- Las Alamos National Laboratory
- California Air Resource Board (FIA)
- ASTM D03 Committee on Gaseous Fuels
- ISO TC197 WG27, 28, 44

## Advanced Detection Methodologies

- HFTO CRADA: GTI, EPRI, Paulsson, Inc. Renewable Innovations, Element One, Boyd Hydrogen
- Emerson, Draeger

## New Market Support: Hydrogen Natural Gas Blends

- SoCalGas; CHS, Blends working group

## Component Failure and Reliability R&D

- UMD, Center for Risk and Reliability (subcontract)
- AVT and Associates (subcontract)

## Hydrogen Safety C&S, Safety Working Groups

- BAM, CHS, IEA Task 43, Hydrogen Safety, HySafe
- SAE FCSC, NFPA, ASTM, UL, ISO, IEC

## NREL Internal

- CFD of H<sub>2</sub> releases, Zhiwen Ma
- NCFCTEC Genevieve Saur
- TEA: Mark Chung
- Green Manufacturing/ Large Scale: Steve Hammond, Jenifer King
- NREL Fire Marshal: Nick Bartlett

## PENDING (multiple partners)

- Hydrogen Hubs
- Large Scale Hydrogen with Private Industry (in negotiation)

The Sensor Laboratory is guided by direct interactions and formal collaborations with hydrogen stakeholders

# DEIA/Community Benefits Plans and Activities

## Commitment to Diversity and Economic/Environmental Justice

- Working with NREL contact for the Faculty-Applied Clean Energy Sciences (FACES) Program, which is aimed at course material development for minority supporting universities
  - One professor identified whose research interests overlap work - hydrogen infrastructure impacts to surrounding communities and hydrogen leakage in pipelines
- Working on hosting 2 women graduate researchers (in-person)
  - Educating next generation of researchers and engineers in hydrogen and renewable energy fields
- Support of John Hopkin's [Summer Academic Research Experience](#) program for under-privileged youth (coordinated by Olivia Robinson).
- Supporting the development of safety and monitoring plans for several pending large-scale hydrogen projects that include outreach to support hydrogen as a clean and safe fuel to community stakeholders.





# Remaining Challenges and Barriers

## Hydrogen Detection for Safety and Emissions

- **Hydrogen Markets Growth:** The decarbonization of energy and manufacturing industries, as envisioned by H2@Scale, is increasing in the U.S. (e.g., the Hubs) and internationally. This has led to increased demand for hydrogen safety resources, such as the NREL Sensor Laboratory. Plus, in the past year two Sensor Lab staff members left to work explore hydrogen opportunities in private industries. This has strained our resources. To address these challenges, we have staffed up with new engineers to carry on with the Sensor Laboratory mission. We will also continue to strive for new collaborations that allow us to synergize our research efforts to maximize the impact of the Hydrogen Sensor Laboratory.
- **Release Hydrogen Behavior:** Outdoor H<sub>2</sub> sensor placement strategies are limited due to the incomplete elucidation of released hydrogen behavior (role of T, wind speed and direction). Released hydrogen modeling will be critical to quantify hydrogen emissions along the value chain to alleviate potential environmental impacts and product lost. In the past year, the Sensor Laboratory team made significant progress on the development of CFD models for hydrogen behavior.
- **Emerging Markets and Advanced Monitoring for Enhanced Safety:** Current H<sub>2</sub> detection approaches may not be optimal for large-scale and emerging markets (e.g., the Hubs and large-scale green manufacturing). Wide area monitoring and stand-off hydrogen detection methodologies are being implemented under the H2@SCALE CRADA (Next Generation Sensor Technologies). This effort includes laboratory performance assessment and field deployments in both outdoor and indoor applications.
- **Low Level Detection:** Hydrogen detection methodologies have strived to preclude the formation of flammable levels of hydrogen. An emerging concern is improved detection capability to inventory hydrogen emissions from a facility for economic reasons, for potential environmental concerns, and potentially as a PHM tool. This will require significantly lower limit of detection relative for conventional safety applications (over 3 orders of magnitude).

# Proposed Future Work

- **Continued development of HyWAM as a research tool and for general active monitoring**
  - Elucidation of released hydrogen behavior to support models through field deployments
    - Develop optimal leak detection methodology to support active monitoring for risk reduction.
    - Support sensor placement guidance
    - Hydrogen release quantification and reverse modeling needs for source location
  - Adapt for lower limits of detection to support emissions monitoring and quantitation
  - Integration of active monitoring into Quantitative Risk Assessment (e.g., HyRAM)
  - Basis for a commercial HyWAM (availability and deployment guidance)
- **Explore advanced detection strategies for hydrogen and gas leak detection for large scale and emerging markets**
  - Advanced standoff methods such as ultrasonic, imaging methods, and fiber optic
  - System monitoring (e.g., P-T, Leak Rates through components) and maintenance strategies (e.g., PHM)
  - HD Markets (including marine, rail, and aerospace)
  - Support community engagement to facilitate engagement
- **Need for lower detection limits to inventory operational and unintended releases to optimize operation efficiency and minimize potential environmental impacts.**

# Summary

**Relevance:** Detection is recognized as a critical element for hydrogen facility safety design and supports risk mitigation. Detection methodologies will support validation of H<sub>2</sub> behavior research. Hydrogen point sensors play a critical role for safety and process monitoring, but other methodologies can be developed.

**Approach:** NREL Sensor Laboratory tests and verifies sensor performance for manufacturers, developers, end-users, regulatory agencies and SDOs/CDOs. NREL deployment activity supports regulatory requirement verification, hydrogen behavior models, and method development for use by stakeholders.

**Accomplishments and Progress:** NREL's R&D accomplishments have supported developers, industry, and SDOs by providing sensor performance and deployment expertise not otherwise available. Development of alternative detection strategies for hydrogen applications have been initiated. HyWAM and advanced detection methodologies deployments at H2@Scale Facilities are being implemented.

**Collaborations:** Collaboration with government laboratories, universities, private organizations and regulatory agencies has leveraged the NREL Sensor Laboratory's success in advancing hydrogen safety sensors and process control.

**Proposed Future Work:** NREL will support hydrogen deployment by the proper implementation of hydrogen sensors and advanced detection strategies. NREL will continue to support science-based codes and standards. This effort will be guided by the needs of the hydrogen community.

# Thank You

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[www.nrel.gov](http://www.nrel.gov)

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