NREL Hydrogen Sensor Testing Laboratory

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National Renewable Energy Laboratory
DOE Project AOP # 6.2.0.502
June 7, 2022

DOE Hydrogen Program
2022 Annual Merit Review and Peer Evaluation Meeting

Project ID: SCS021

Project Goal
Hydrogen Sensor Testing Laboratory

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

- Sensors are a critical element for a facility safety system by providing an early indication of unintended releases.
- Sensors can be used in process control applications (e.g., FQ verification).
- The Sensor Laboratory provides developers and end-users with an unbiased resource to validate sensor performance to application requirements.
- The Sensor Laboratory facilitates deployment through support of codes and standards development and safety research.
- The Sensor Laboratory supports advanced strategies for early leak detection.

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
- FY21 DOE funding (if applicable): $925,000
- FY22 planned DOE funding: $525,000
- Total DOE funds received to date*: $5,365,000

* Since the project started

Partners

- Project lead: William Buttner, NREL
- Co-PI(s): M. Post, J. Thorson, K. Hartmann
- Partner organizations
  - AVT and Associates, Sensor Placement R&D (subcontract)
  - Element One, Inc., Wireless low power sensor development (subcontract)
  - KWJ, Inc.: TCF CRADA
  - LANL (Fuel Quality Sensor)
  - SPPs: Shell, Amphenol, CARB, Element One, Paulsson, Power Roll (pending)
  - University of Maryland, Center for Risk Assessment and Reliability

Relevance/Potential Impact

Role of Hydrogen Sensors

Safety--Impact of Undetected Released H_2

- Potential for fire or worse
- Early detection minimizes impact
- Need for detection & how to properly implement to assure early detection
- Detection can provide risk mitigation credits

Hydrogen sensors are the most common way to detect unintended hydrogen releases.

Process Control (FQ Sensors)

- Monitor for fuel impurities or constituents (e.g., H2 in natural gas)
- Prevent FCEV damage

Identify out-of-compliance hydrogen before dispensing into FCEV.

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

Hydrogen Sensors represent a critical element in a facility safety and operational systems but must be reliable and properly deployed to be effective.

Approach

The NREL Sensor Laboratory

Traditional Focus (H_2 Sensors)

- Sensor performance evaluation for specific metrics (prescriptive warning & alarm levels from codes)

Emerging Focus (Active Monitoring)

- Early warning indication for out-of-normal conditions
- Integration of active monitoring into risk mitigation
- Modelling & empirical sensor deployment studies

HyWAM/Standoff Methodologies (advanced strategies)

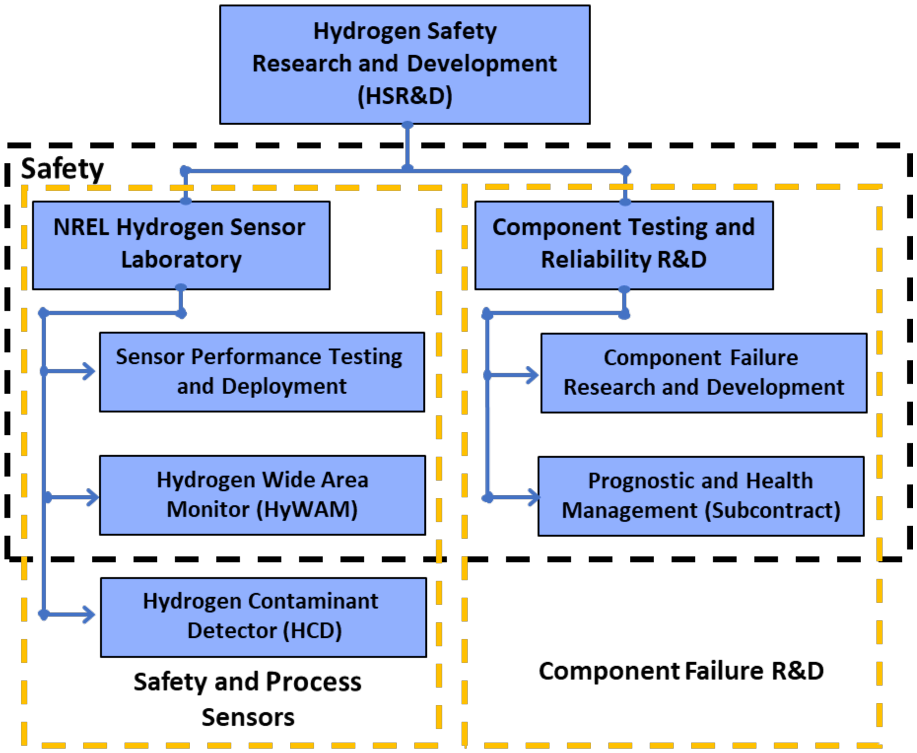
- Advance TRL for HyWAM/standoff methods for H_2

Support New and Emerging Markets

- H2@Scale / Hydrogen Earth Shot (new markets—Heavy Duty, H2-NG Blends, energy storage)

Implementation Strategies

- Strategic national and international partnerships (sensor developers, end-users, regulators, modelers)



Approach
The NREL Sensor Laboratory

Unique Sensor Testing and Deployment Capability

Provide unique sensor performance capability

- **Safety Sensors (Safety Sensor Test Apparatus, SSTA**
  - **Topical Studies / Customer applications (safety/environment)**
  - **Emerging technologies and markets**
  - **Support HyWAM**
- **Process Sensors and Process Control Applications (Process Gas Characterization Apparatus, PGCA)**
  - **NEC-compliant for non-listed devices (FQ, H2-NG blends)**
- **Access to HITRF and ARIES (deployment studies)**
  - **Leak Rate Quantification Apparatus—with leak on demand**

Outreach

- **Direct collaboration with stakeholders (WFO)**
- **CDOs/SDOs, Safety Groups (Center for Hydrogen Safety)**
- **Conferences and Workshops (e.g., *The NREL Sensor Laboratory: Status and Future Directions for Hydrogen Detection,* 2021 ICHS).**

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

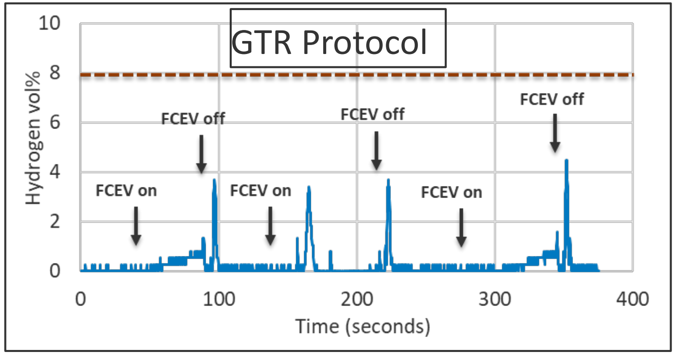
The SSTA (part of the testing capability of the NREL Sensor Laboratory)

Hydrogen Infrastructure Testing and Research Facility (HITRF)

Accomplishments and Progress
FCEV Exhaust Gas Analyzer

- **FCEV Exhaust Gas Analyzer to verify compliance to GTR 13 with Environment Canada (ECCC) and Transport Canada, (TCa).**
  - **Sensor & gas collection system to quantify exhaust hydrogen**
  - **Critical metrics: measurement range, response time**
  - **Operational challenges: Condensed water in exhaust**
- **Laboratory Testing and Evaluation**
  - **Designed new gas sampling system for delivery of dehumidified gas to sensor**
  - **Verification of metrological metrics (RT < 300 ms)**
  - **ROI-21-126 *Analyzer and Sample Collection System for Hydrogen Fuel Cell***
- **Demonstration on FCEV in collaboration with ECCC and TCa**
  - **Successful operation of the analyzer on an FCEV to measure H_2 transients and to mitigate water entrainment**
  - **Joint paper at the 2021 ICHS.**
  - **Ongoing testing on additional FCEVs supplied by TCa**

FCEV Exhaust measurements (performed at ECCC)



Regulatory requirements must have a method for verification. The NREL FCEV exhaust analyzer can confirm compliance to GTR-13.

Accomplishments and Progress
Hydrogen Wide Area Monitoring (HyWAM)

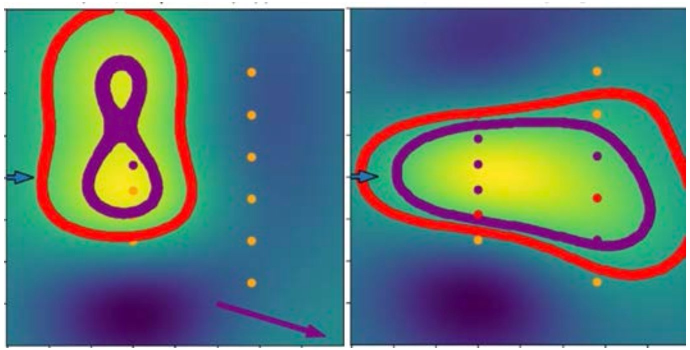
Supports R&D of Hydrogen Version

- **Deployed in HSE PRESLHY Studies for cold plume profiling (FY20)**
  - **PRESLHY WP3 - WP5 testing, data in PRESLHY repository**
    - **HSE WP3-WP5 contributions to the Dissemination Conference**
    - **Joint NREL-HSE paper at 2021 ICHS.**
    - **Ongoing analysis of WP5--combustion data (T vs. vol% H2)**
- **Ruggedized versions deployed at NREL (GH2 venting)**
  - **ESIF rooftop (investigate entrainment into air Intake)**
    - **Assessment of metrological performance metrics of HyWAM**
  - **Additional LH2 deployments planned (Commercial LH2 site, SNL LH2 Release, Investigating Advanced Sensors CRADA).**
- **Basis for a Commercialized Version of HyWAM**
  - **Commercialization strategy through DOE TCF Program**
  - **Design features under development with private partner**

Hydrogen Wide Area Monitoring (HyWAM)
The quantitative spatial and temporal 3-dimensional profiling of hydrogen releases (planned and unintentional).

HSE PRESLHY LH2 Release with combustion(WP5)

L: 300 and 450^{o}C T contours; R: 4 and 10 vo% H2 contours

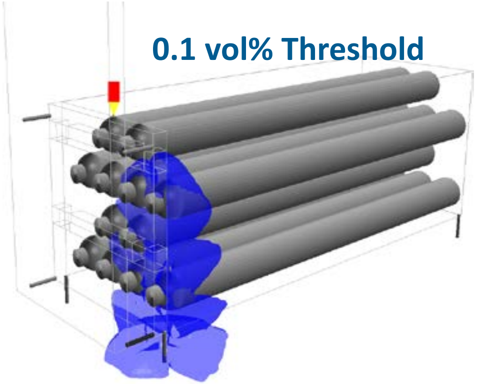


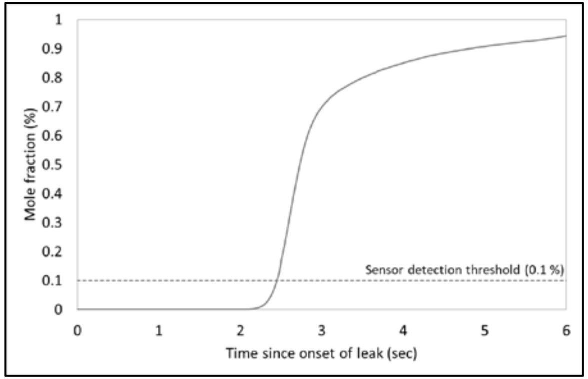
HyWAM deployment on ESIF (entrainment)

Accomplishments and Progress
Sensor Placement within Enclosures

- **Collaboration with AVT and Associates**
- **Developed CFD models of H2 dispersion in small enclosures, validated by NREL HyWAM**
- **CFD-informed on H_2 dispersion HyRAM layer model generates more accurate over pressure calculations**
- **CFD modeling of effects of ventilation and H2 concentration distribution in big and small enclosures will inform NFPA 2 Table on HEE (recommendations under review)**
  - **Mechanical ventilation significantly reduces build up of hydrogen and eliminates the formation of hazardous flammable cloud**
  - **CFD modeling showed that early detection is possible within a few seconds from the onset of the leak**

0.1 vol% Threshold





Time needed to detect the leak for credible leak scenario

Understanding released hydrogen behavior can guide sensor deployment for improved detection of unintended releases.

Accomplishments and Progress
(Hydrogen Contaminant Detector—Process Sensors)

Stringent Fuel Quality Requirements (SAE J2719/ ISO 14687 2019)
- Verification required for commercial dispensing
- Need for real-time verification vs. remote analysis

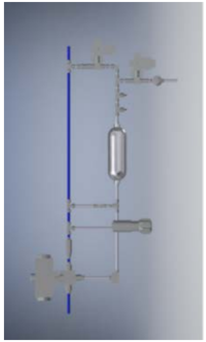
Identification and laboratory evaluation of HCDs
- LANL CO Sensor (commercial prototype); multiple gas analyzer (FTIR)

Integration of HCD into the NREL dispenser (HCD-Interface)
- HCD-Interface designed and demonstrated at working pressures (including automated sample collection and delivery to HCD)
- Integration points into (NREL) dispenser plumbed

Outreach
- ***Automated Monitoring of H2 FQ at Commercial Hydrogen Stations with On-Site HCD***, **ASTM Workshop "In-Line Hydrogen Fuel Analyzers" (Dec 21)**

Plans
- Demonstration at NREL Dispenser, Deployment at Commercial Station
- Additional HCDs to be incorporated into the project (e.g., moisture)

On-Line hydrogen contaminant detection will help prevent dispensing of contaminated fuel.


Hose Venting (HP)


Sample capture (LP)

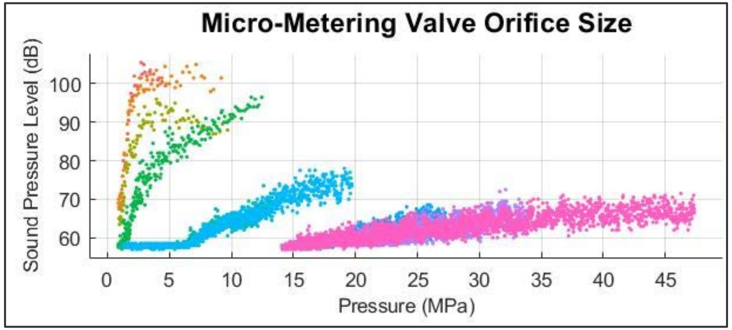

Gas flow to HCD (ambient)

Accomplishments and Progress
(Alternative Leak Detection Strategies)

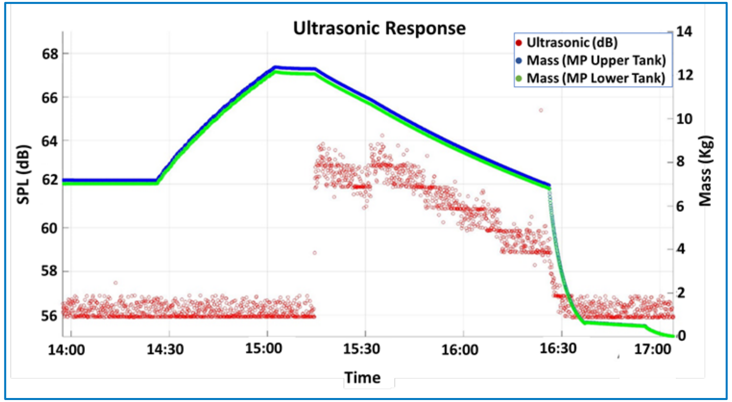
Ultrasonic Leak Detection (ULD):

- **Standoff leak detection based on acoustic signatures**
  - **"Instantaneous" response over broad area**
  - **Alarm thresholds optimization (intensity/time)**
- **Demonstration within HITRF**
  - **Characterizing signatures for small leaks**
  - **Responded to an unintentional event (remote)**
  - **Optimization is ongoing**
- **Deployment at commercial HD fueling facility (May 2022)**

Point sensors represent just one strategy to detect hydrogen leaks. There are other methods with potential advantages.



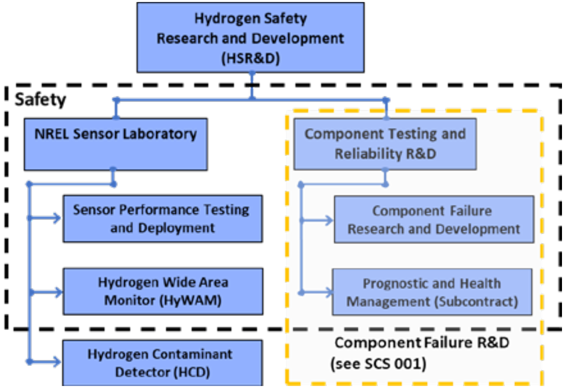
ULD response to calibrated orifices((0.032 mm to 0.357 mm

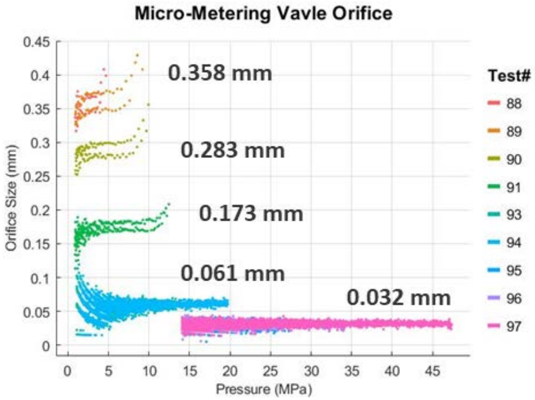


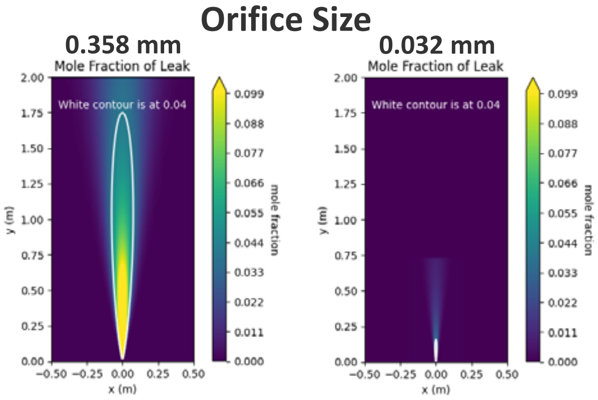
ULD response of an unintended H2 release within HITRF

Accomplishments and Progress
Hydrogen Leak Rate Quantification

- Used the LRQA to characterize leaks of varying orifice size
  - Component reliability R&D task in collaboration with UMD
  - Ascertain the severity of leaks through failed components
  - Micro-metering valve used to control the leak office size
  - Determined the mass flow rate and equivalent orifice size of leaks
  - Used HyRAM to model the leak plume dispersion for the various orifice sizes at a nominal upstream pressure of 55 MPa







Hydrogen leaks characterized by source parameters (size, pressure)- see *Component Reliability R&D* (AMR SCS001), Hartmann et al.

Accomplishments and Progress

(Internships within the NREL Sensor Laboratory)

Continued mentoring of undergraduate scientists and engineers within the NREL Sensor Laboratory

- Mutually beneficial; Real-world research experience in H_2 and alternative energy R&D
- Assigned as "technical lead"
  - Interactions with clients
  - Good publication record
- FY1 – FY 22 interns:
  - Tashi Wischmeyer (wireless HyWAM), currently at Hitachi Energy
  - David Pearman (GTR, Sensor Testing), graduated and hired by NREL
  - Ian Palin (Sensor Testing Support and Analysis)
- Successful careers
  - Several have hired on at NREL (FTE & Consultants)

(Former) Intern Dave Pearman working on the NREL HCD-Interface hardware

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:

- This is a highly productive project, with excellent growth potential into being proactive in applying sensor technologies to develop low-risk systems. This is particularly important as we move to H2@Scale. The collaborations developed are large in number and broad in scope, and each one is relevant to improving the deployment of low-risk systems. In particular, the attention to WAM, its improvement over time, and its application to liquid behavior is commendable. The project's further development is eagerly awaited.

Reply:

The NREL Sensor Laboratory continues to explore collaborations to efficiently support the safe implementation of hydrogen infrastructure and new markets as envisioned by H2@Scale and the Hydrogen Earth Shot. In FY21, we were able to work remotely with some of our partners (e.g., the FCEV Exhaust Analyzer at ECCC). However, the inability to travel due to COVID restrictions hampered other projects (e.g., HyWAM for LH2 releases). Travel restrictions are lifting, and deployment plans are now being developed for both HyWAM (at LH2 facilities) and ULD.

Accomplishments and Progress: Response to Previous Year Reviewers' Comments

Project Weaknesses:

- The project seems to be supporting other projects more than developing and proving technologies that could more immediately affect the rollout of hydrogen infrastructure. For example, the HyWAM technology is useful for research, but it is not in a useful state for deployment to active systems. The team should consider how this technology can be expedited for real-world use instead of just for scientific purposes. From a commercial availability perspective, there does not seem to be a significant increase in the capability or a decrease in the cost for sensing technology for smaller systems (e.g., typical fuel station sizes). Perhaps there is a more effective way to get new technology to market, while being more cost-effective and for smaller systems.

Reply:

The NREL Sensor Laboratory has been looking at methods of detecting and quantifying hydrogen leaks other than through point sensors. Our team provided support to optimize the use of P-T monitoring of hydrogen storage tanks within NREL to detect unintended releases. We are also looking at the quantitative characterization of leaks to ascertain risk levels of failed components. As for commercialization of HyWAM, we are working with a private company through the DOE TCF program to support the design of a commercial HyWAM.

Collaboration and Coordination

H_2 Detection (Performance Assessment & Develop.)
- Element One, Inc. (subcontract)
- Emerson System (Ultrasonic Leak Detectors) NDA
- Draeger (Bailment Agreement)
- Amphenol (TSA)

Infrastructure Sensor Deployment and Utilization
- Shell (TSA)
- Center for Hydrogen Safety
- Paulsson (SPP, pending)
- NFPA 2 H_2 Storage Safety Task Group
- ISO TC 197

HyWAM Development and Deployments (Private)
- KWJ, Engineering (TCF CRADA)
- Plug Power (NDA)

Vehicle Support
- Ford Motor Company (NDA)
- SAE Fuel Cells Standards Committee
- ASTM D03 Gaseous Fuels

Government Partnerships
- TCa/ECCC (FCEV Safety)
- Health and Safety Executive (HSE) (NDA)
  - Support of PRESLHY: LH2 behavior/HyWAM
- Los Alamos National Laboratory (Transfer Agreement for)
- Sandia National Laboratory (HyWAM; HyRAM)
- National Energy Technology Laboratory
- BAM Institute (Germany)—NDA

Support of Emerging Markets and Applications (Safety)
- SBIR Collaborations (multiple) (H_2-NG Blends)
- CHS WG on H_2 -NG Blends (Chair of Detection subgroup)
- Blue Origins, KSC (aerospace)
- H2@Scale CRADA “Next Generation H2 Detection, pending, (Partners: GTI, EPRI, Paulson, Boyd Hydrogen, Renewable Innovations, Element One).

The NREL Sensor Laboratory--A resource to the H_2 community
- **Infrastructure, vehicle, and new markets**
- **Sensor developers and end-users**
- **Formal and informal agreements; Available for WFO**

Remaining Challenges and Barriers

Hydrogen Detection for Safety Applications

- **Sensor Deployment Guidance/Release Hydrogen Behavior:** Outdoor H_2 sensor placement strategies are limited due to the incomplete elucidation of released hydrogen behavior (role of T, wind speed and direction). As in FY20, numerous deployments to characterize H2 release behavior and to validate HyWAM instrumentation were again cancelled in FY21 due to COVID, which hampered productivity. Such restrictions do not appear to exist in mid-FY22.
- **Integration of Active Monitoring as a Risk Reduction Strategy:** A science-based integration of detection into QRA (e.g., such as through HyRAM) for quantitative risk credit remains lacking. Preliminary integration of leak rates as measured by the LRQA into HyRAM has initiated.
- **Active Monitoring for Enhanced Safety/HyWAM**: An economical HyWAM with the necessary metrological and deployment characteristics to support active monitoring does not exist. Viable stand-off approaches to supplement the NREL HyWAM have not been validated but are being investigated. This was a specific topic area of a recently funded H2@SCALE CRADA (Next Generation Sensor Technologies), which include technology performance assessment in the laboratory and in field deployment at H2@Scale facilities for both outdoor and indoor applications.
- **Emerging Markets:** Current H2 detection approaches may not be optimal for large-scale and emerging markets (e.g., H2@Scale, including H2-NG blends, new production methods, large scale storage and hydrogen pipelines).
- **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 both economic reasons and for potential environmental concerns, which will require significantly lower limit of detection relative for conventional safety applications (possibly 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**
  - **Integration of active monitoring into QRA (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**
  - **Complex mixtures (e.g., H2 in Natural Gas admixtures)**
  - **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)**

- **Need for lower detection limits to inventory operational and unintended releases to optimize operation efficiency and minimize potential environmental impacts.**

Summary

Impact of the COVID-19 Shutdown: Travel and facility access restrictions impacted NREL Sensor Laboratory efforts. However, by adapting our focus, progress was made exploring advanced detection strategies and to evaluate the role of detection for emerging market safety. COVID restrictions are now being lifted.

Relevance: Detection is recognized as a critical safety element for hydrogen facility risk mitigation as a tool to support H_2 behavior research and as an element in a deployed active monitoring safety system. 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 has been initiated. HyWAM and advanced detection methodologies deployments at H2@Scale Facilities are already planned.

Collaborations: Collaboration with government laboratories, universities, private organizations) has leveraged NREL'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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NREL/PR-5700-82757

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Hydrogen and Fuel Cell Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

NREL
Transforming ENERGY

Technical Backup and Additional Information

Technology Transfer Activities

- Record of Invention “Analyzer and Sample collection system for Hydrogen Fuel Cell Exhaust Analyzer” W. Buttner, D. Pearman, M. Post, K. Hartmann, J. Thorson; Submitted April 2021.
- Technology Commercialization Fund Project “Commercialization of the NREL Hydrogen Wide Area Monitor (HyWAM)” CRADA CRD-18-00784) with industrial partners (KWJ, First Element) to commercially develop a effective HyWAM (through April 2023)

Publications and Presentations

Publications

Journal Articles:

"Development of risk mitigation guidance for sensor placement inside mechanically ventilated enclosures – Phase 1," Tchouvelev, A.V., Buttner, W.J., Melideo, D., Baraldi, D., and Angers, B., Int. J. Hydrog. Energy 46(23):12439–12454, 2021, doi:10.1016/j.ijhydene.2020.09.108.

"Hydrogen wide area monitoring of LH2 releases" Buttner, W., Hall, J., Coldrick, S., Hooker, P., Wischmeyer, T., Int. J. Hydrog. Energy., 46(23):12497-12510.

"Characterization of a selective, zero power sensor for distributed sensing of hydrogen in energy applications," Wischmeyer, T., Stetter, J.R., Buttner, W.J., Patel, V., and Peaslee, D., Int. J. Hydrog. Energy 46(61):31489–31500, 2021, doi:10.1016/j.ijhydene.2021.07.015.

"Critical Review and Analysis of Hydrogen Safety Data Collection Tools," Madison West, Ahmad Al-Douri, Kevin Hartmann, William Buttner, Katrina M. Groth (in press, Int. J. Hydrog. Energy)

Publications and Presentations

Talks and Presentations

DOE AMR (June 7-11, 2021)

Buttner, William, Post, M., Hartman, K., Thorson, J., Wischmeyer, T., and Pearman, D., "SCS021: NREL Hydrogen Safety Sensor Laboratory," U.S. Department of Energy Hydrogen and Fuel Cells Program 2018 Annual Merit Review and Peer Evaluation, 2021 Annual Merit Review Proceedings, Virtual, 2021.

Hartmann, K., Correa-Jullian, C., Thorson, J., West, M., Buttner, William, and Groth, K., "SCS001: Component Failure R&D," U.S. Department of Energy Hydrogen and Fuel Cells Program 2018 Annual Merit Review and Peer Evaluation, 2021 Annual Merit Review Proceedings, 2021.

William Buttner, Post, M., Koleva, Mariya, and Hartmann, K., "H2042: Hydrogen Contaminant Detector," U.S. Department of Energy Hydrogen and Fuel Cells Program 2018 Annual Merit Review and Peer Evaluation, 2021 Annual Merit Review Proceedings, Virtual, 2021.

Tchouvelev, A.V., Buttner, William, and Angers, B., "SCS027: Guidance for Indoor H2 Sensor Placement," U.S. Department of Energy Hydrogen and Fuel Cells Program 2018 Annual Merit Review and Peer Evaluation 2021 Annual Merit Review Proceedings, Virtual, 2021.

Sprik, S., Buttner, W.J., Saur, G., Peters, M., Onorato, S., and Koleva, Mariya, "H2021: California Hydrogen Research Consortium," U.S. Department of Energy Hydrogen and Fuel Cells Program 2018 Annual Merit Review and Peer Evaluation, 2021 Annual Merit Review Proceedings, 2021.

Publications and Presentations

Talks and Presentations
Conference Papers (International Conference on Hydrogen Safety):
Buttner, W.J., Wischmeyer, T., Hall, J., Coldrick, S., Hooker, P., and Thorson, J., "'Hydrogen Wide Area Monitoring of LH2 Releases at HSE for the PRESHLY' Project (ID 153); Proceedings of the 2021 International Conference on Hydrogen Safety, Edinburgh, Scotland, 2021.

Andrei Tchouvelev, Buttner, W.J., and Angers, B., "Development of Risk Mitigation Guidance for Sensor Placement Indoors and Outdoors – Phases 2 and 3; Proceedings of the 2021 International Conference on Hydrogen Safety, Edinburgh, Scotland, 2021.

Hartmann, K., Camila Correa-Jullian, Buttner, W.J., Groth, K., and Thorson, J., "'Hydrogen Component Leak Rate Quantification for System Risk and Reliability Assessment through QRA and PHM Frameworks', (ID 157); Proceedings of the 2021 International Conference on Hydrogen Safety, Edinburgh, Scotland, 2021.

Post, M.B., Buttner, W.J., Hartman, K., Thorson, J., Pearman, D., and Wischmeyer, T., "'The NREL Sensor Laboratory: Status and Future Directions for Hydrogen Detection', (ID 176); Proceedings of the 2021 International Conference on Hydrogen Safety, Edinburgh, Scotland, 2021.

Pearman, D., Buttner, W.J., Aaron Loiselle-Lapointe, Aaron Conde, Post, M.B., and Hartmann, K., "(ID157) 'Safety Compliance Verification of Fuel Cell Electric Vehicle Exhaust', Proceedings of the 2021 International Conference on Hydrogen Safety, Edinburgh, Scotland, 2021.

Publications and Presentations

Other Talks and Presentation

Thorson, J., Buttner, W.J., Hartmann, K., Post, M., Wischmeyer, "Past, Present, and Future of Hydrogen Wide Area Monitoring Research at NREL", Codes and Standards Tech Team Meeting November 18, 2021).

Post, M., Buttner, W., Koleva, M., Hartmann, K., "Automated Monitoring of Hydrogen Fuel Quality at Commercial Hydrogen Stations with On-Site Hydrogen Contaminant Detectors (HCDs)", ASTM Committee D03 on Gaseous Fuels Workshop on In-Line Hydrogen Fuel Analyzers (December 8, 2021)

Buttner, W., Hartmann, K., Post, M., Thorson, J., Pearman, D., Palin, I., Hydrogen Releases Quantification-I: Sensors and Detection Tools; II: Leak Rate Quantification, Invited Talk to the Clean Energy Joint Undertaking (Virtual) Workshop On Environmental Impacts of Hydrogen (March 31-April 1, 2022)

Buttner, W., Hydrogen Leakage Quantification Workshop (virtual), Environmental Defense Fund invited Workshop, (February 11, 2022) Invited Participant

Summary: Advancement from 2021 of ongoing projects and activity

Project/Activity	FY 21 Status	FY 22 Advancements
HyWAM (Outdoor Applications)	The NREL HyWAM successfully profiled LH2 releases performed at HSE under PRESLHY; HyWAM data was delivered PRESLHY program office for dissemination. HSE used the NREL HyWAM to profile releases of H2-NG blends (HyDeploy). Support of other deployments identified in FY20 were cancelled due Covid travel restrictions. Hardware upgrades include robust packaging in weather-proof instrument enclosures. Deployment at a commercial LH2 facility is pending	NREL HyWAM data was uploaded into the PRESLHY data respository maintained by KIT. Several of HSE talks to the PRESLHY dissemination Workshop (May 5, 2021). A joint paper was presented at the ICHS. NREL and HSE are currently analyzing WP5 (Combustion) data to develop correlations between temperature profiles and hydrogen levels. Other external deployments were hindered due to COVID travel restrictions. HyWAM hardware embellishments have been implemented. Deployments are LH2 facilities are pending.
HyWAM (Indoor, GH2/He) -- Indoor Hydrogen Behavior	Contribution to NFPA 2 revision cycle (sensor placement guidance). Developed new text for ANNEX M3 Location of Gas Detectors to Effectively Detect Hydrogen. Contribution to enhancement of HyRAM. Continued work on incorporation of CFD modeling results into HyRAM to enhance the existing algorithm for the enclosure layer model and more accurate overpressure calculations. Adapt HyWAM for NREL program in support of the "Smart Lab" validation	On-going collaboration with AVT and Associates to elucidate hydrogen behavior in enclosures to support sensor placement guidance and to minimize risk through QRA. CFD may provide guidance for fast leak detection. The work is continuing to integrate hydrogen modelling into HyRAM for more accurate input on H2 concentrations in enclosures. Recommendations for NFPA 2 were proposed and are being reviewed.
FCEV Exhaust Analyzer, support of GTR 13	Continued collaboration with ECCC and TCa for FCEV Exhaust analyzer demonstration. A modified gas sampling system the provided passive water mitigation was demonstration on a laboratory fixture with deployment on a FCEV at ECCC planned for June. A ROI was submitted for the gas sampler.	A modified gas sampling interface was developed that delivers dehumidfied sample to the sensor while maintaining accuracy, range, and response time requirements. The system was deployed at ECCC and successfully measured FCEV exhaust. This was a topic of a paper at the 2021 ICHS. Additional FCEV deployments are planned
Sensor Testing and Evaluation	On-going sensor evaluation in support of developers and end-users, but with new markets (e.g., battery safety, aerosp	Sensor Performance Testing and Evaluations continue to be a unique capability of the NREL Sensor Laboratory. This activity currently supports HyWAM and several H2@Scale Markets (e.g., sensors for hydrogen-natural gas blends)
CDO/SDO Committees	Continued participation in critical SDO/CDOs including ISO, SAE, NFPA 2, ASTM, and to support regulatory agencies (DOT, TCa). Sensor guidance document was formally presented to NFPA 2 Technical Committee.	Continued participation in critical SDO/CDOs including ISO, SAE, NFPA 2, ASTM, UL and to support regulatory agencies (DOT, TCa). Sensor guidance document was formally presented to NFPA 2 Technical Committee and is under review.
FQ Verification	Completed laboratory metrological performance evaluations of two HCDs and obtained baseline calibration curves for target contaminants. Developed a HCD-I and demonstrated its operational features (automated sample collection and sample delivery to HCD at controlled flow and ambient P. Approval to install into dispenser once site construction is completed (projected start date: June 2021)	The HCD evaluated in FY21 are now being integrated into the NREL hydrogen dispenser using a custom-designed interface that automatically samples high pressure hydrogen from hose venting and stores it at medium pressure for subsequent delivery at ambient pressures to HCD. The system is to be demonstrated at the NREL dispenser and then deployed at commercial fueling faciliities.
Component Reliability R&D	Started testing failed components and calibrated orifices on LRQA to elucidate size and potential consequences of leaks. Adapted the LRQA for "leak-on-demand" capability to support stand-off detection methods. Initiated QRA and PHM applications to high pressure components via a subcontract with UMD (Prof. Katrina Groth); subject of Master's Thesis "*Data Requirements to Enable PHM for Liquid Hydrogen Storage Systems from a Risk Assessment Perspective*" (C. Julian) .	Hydrogen leak rate determnation through failed components is continuing. Procedures to calibrate the system using calibrated orifices have been developed. The LRQA also serves as a leak-on-demand to test outdoor hydrogen detection methods, including ultrasonic methods.Subject of Master's Thesis "Development of a Reliability Data Collection Framework for Hydrogen Fueling Station QRA", Madison West (Research Advisor: Katrina Groth)+G2.
Advance Hydrogen Detection Methodoloyg		NREL Sensor Laboratory has intiated alternative methods to detect hydrogen releases and to ascertain risks, including advance detectin strategies (e.g., ultrasonic leak detection applied to hydrogen systesm, system monitoring, and the quantitation of hydrogen leak rates.

Much of the NREL Sensor laboratory FY21 is based on ongoing activity and naturally builds off the past accomplishments

NREL Sensor Laboratory
Testing Capability

The NREL Safety Sensor Testing Apparatus (SSTA)

- Metrological assessment to critical performance specifications and impact of environmental parameters.
- Typically test sensors for safety applications

The NREL Process Gas Characterization Apparatus (PGCA)

- Sensor testing to hydrogen, methane, NG, and blends.
- Fuel Quality Verification (H2 Contaminant Detector--HCD)
- Will support H2@Scale (H2 -NG blends)

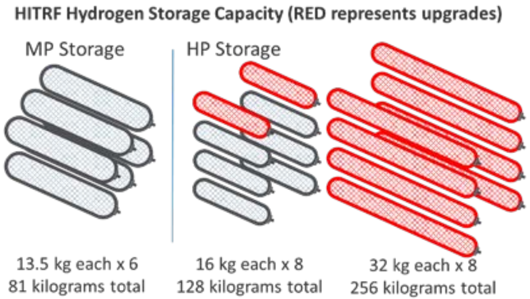
The Leak Rate Quantitation Apparatus (Leak on Demand Apparatus)

- Provides a release that mimics real-world leaks under working conditions
- H2, CH4, NG and Blends
- Testing of advanced leak detection technologies in real-world conditions

Sensor testing is a unique NREL capability
Verification of sensor performance is critical to assure end-user confidence

NREL Sensor Laboratory

Available Resources: Hydrogen Infrastructure Testing and Research Facility

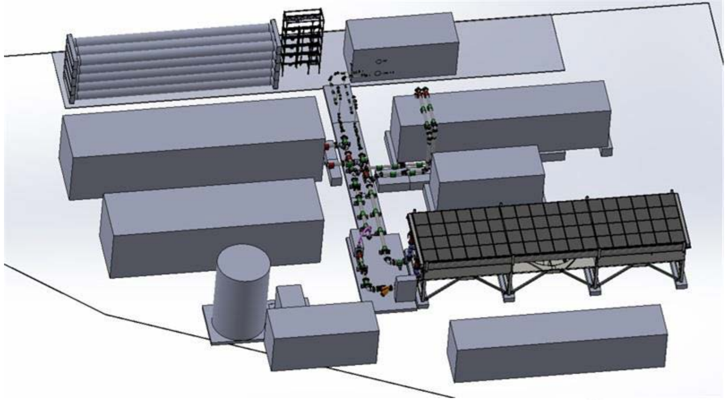


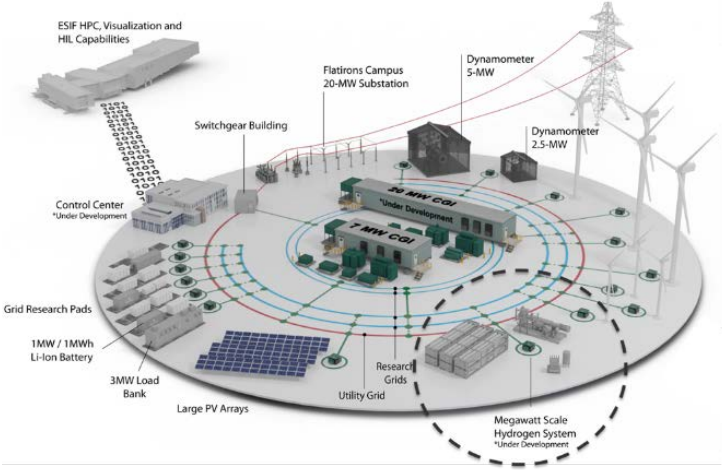
The NREL Hydrogen Infrastructure and Testing Research Facility (HITRF)

- Integrated R&D test facility with fully functional H_2 dispensers with on-site storage and production
- Supports HPPS component, systems, and processes R&D
- Site for ultrasonic hydrogen leak detection demonstration
- Recently upgrades (March 15, 2020 through December 19, 2022) increased high-pressure (HP) storage to accommodate high-through-put (Heavy Duty) fueling R&D

NREL Sensor Laboratory

Available Resources: Advanced Research for Integrated Energy Systems (ARIES)

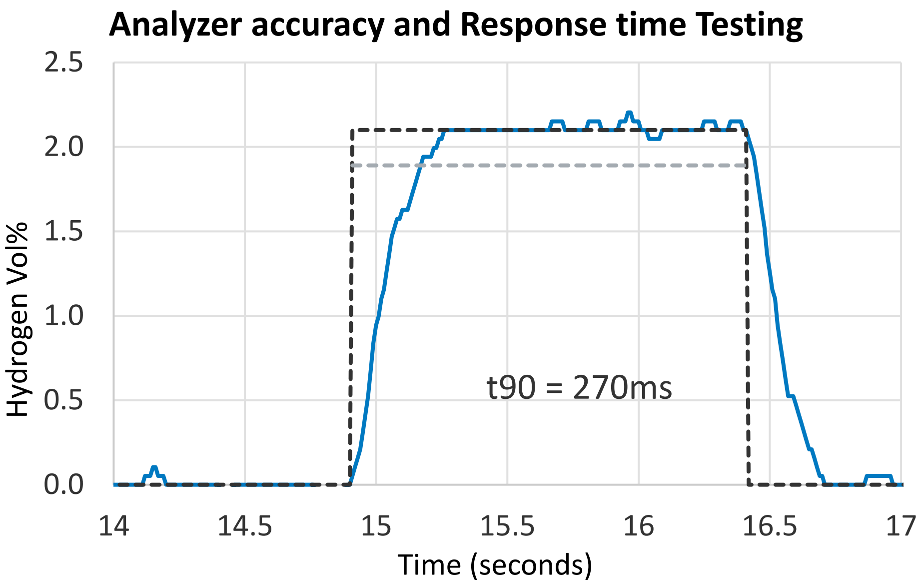


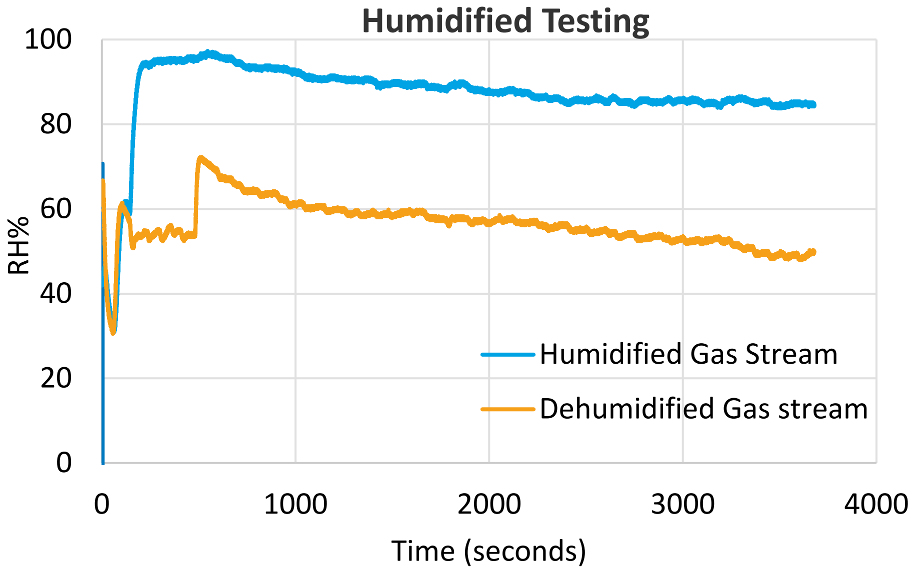


- Large-scale testbed for integrating renewable energy (wind, solar, H2)
  - "Instrumented" facility
- Large-scale hydrogen production and storage
  - Commissioning Q2 2022
  - H2 available for release studies
- Subject of 2021 H2@Scale CRADA Call
  - "Advanced" leak detection strategies
    - Enclosed and Open release scenarios
    - Compared to "point sensors)
  - AIRES will be one demonstration site
    - Digital Twin / Modeling of Hydrogen Process
    - Controlled releases
    - Monitored by HyWAM and other methods (model validation)
    - Supplemental Monitors (wind speed and direction)

See AMR TA048
"ARIES / Flatirons Facility - Hydrogen System Capability Buildout"

FCEV Exhaust Analyzer: Laboratory Demonstration of Response Time, accuracy, and dehumidification of sample





- Hydrogen exposures demonstrate compliance to GTR response time requirements and accuracy.
- Incoming exhaust test gas (60°C-70°C, saturated humidity with water droplets) is dehumidified (40%-60%, 25°C) for analysis.

GTR response time requirements are met without interference from water entrainment