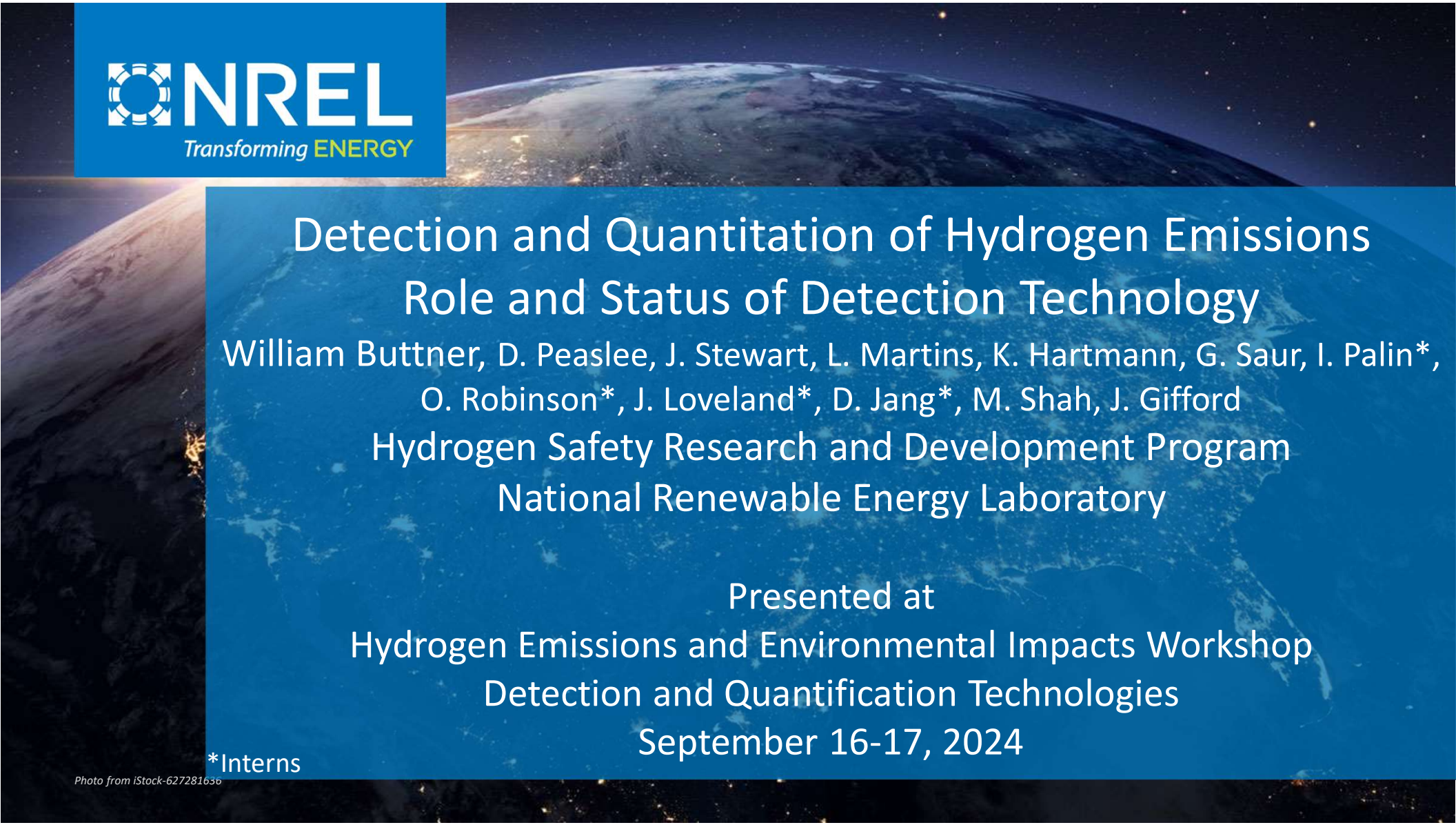


Detection and Quantitation of Hydrogen Emissions
Role and Status of Detection Technology

William Buttner, D. Peaslee, J. Stewart, L. Martins, K. Hartmann, G. Saur, I. Palin*, O. Robinson*, J. Loveland*, D. Jang*, M. Shah, J. Gifford

Hydrogen Safety Research and Development Program

National Renewable Energy Laboratory

Presented at

Hydrogen Emissions and Environmental Impacts Workshop

Detection and Quantification Technologies

September 16-17, 2024

*Interns

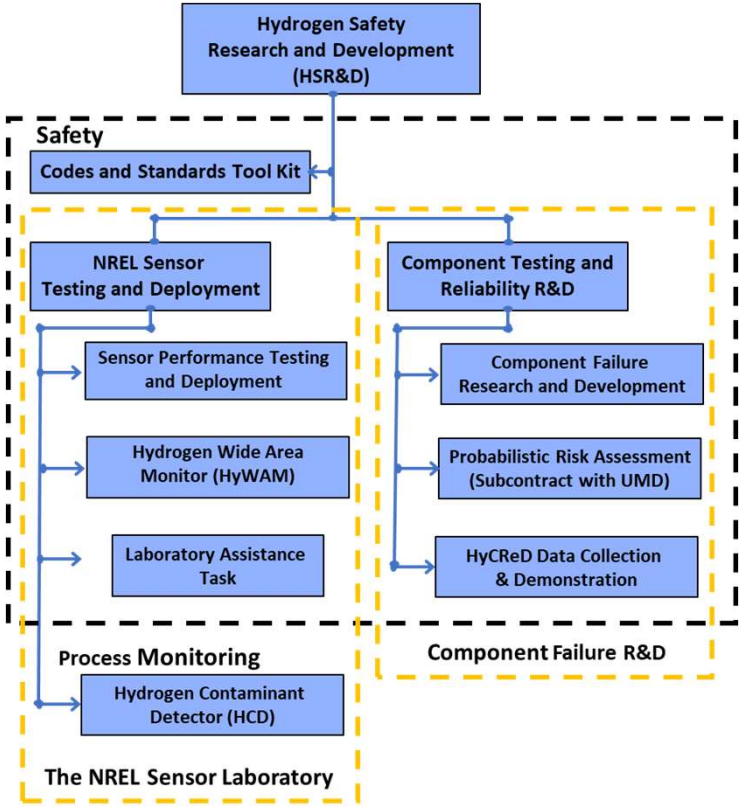
Photo from iStock-627281636

NREL HSR&D Program Organization
The NREL Sensor Laboratory, Component Reliability, and SCS

NREL HSR&D Program

- The NREL Sensor Laboratory
  (H_2 Detection Technology Development & Deployment)
- Component Testing and Reliability
  (Reliability of H_2 systems and components)
- Support of Hydrogen Codes and Standards

Detection and Mitigation of the Impacts
of unintentional and operational Hydrogen Releases



The NREL HSR&D Program
was established to facilitate the **safe and efficient** utilization of hydrogen.

Component Reliability R&D
(mitigate the occurrences and impact of component failures)

- Infrastructure down time and its consequences
  - Down time = lost of profits
  - Unplanned maintenance (vs. PHM)
  - Adverse impacts of public perception and acceptance of H_2
  - Minimizes Loss of product (approaching $40/kg at the pump)
- Concerns with unplanned hydrogen releases
  - Failed components can lead to serious events (Safety Issues)
  - Hydrogen losses can have environmental impact
- Strategic Partnerships ands community outreach
  - Need Data from stakeholders

Pathway for Mitigation of Risks (probabilistic risk reduction)

Risk = Frequency of Occurrence * Consequences

NREL Transforming ENERGY

UNIVERSITY OF MARYLAND

The NREL Component Reliability R&D Program supports H_2 Infrastructure reliability

Hydrogen Detection--What is a sensor? Sensing Element vs. Sensor vs. Analyzer

Sensing Element: Interaction with stimuli and transduction into electrical signal

- Different Platforms (CGS, TC, EC, MOX, Palladium, etc., advanced methods)

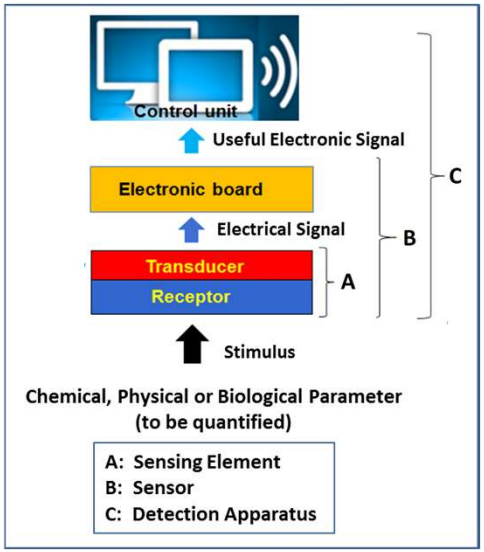
Sensor: Provides quantitative information

- Sensing Element(s) integrated with electronic circuity (convert sensing element electrical response to useful signal, analytical signal optimization)

Detection Apparatus (Analyzer, etc.):

- Quantification, Alarms, and Control Functions

Sensor vs. Sensing Element vs. Analyzer



Sensing Element ($10 to $100)
(analog signal)

vs.

Sensor ($50 to $500)
(vol% H_2)

vs.

Analyzer (>$500)
(Control Functions)

The term "*sensor*" can have different meanings among stakeholders within the hydrogen community.
Practical definition: A hydrogen sensor provides quantitative information on the presence and amount of hydrogen.

Overview of Hydrogen Releases

Operational Hydrogen Releases

- Transfer Processes, 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., PRV activation)
- Breaches / component failure
- Size considerations
  Small leaks ("inconsequential" amounts for safety)
  Larger Leaks (potential safety concerns)

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

LH2 Venting following delivery

Small leak identified by a soap solution

The NREL Sensor Laboratory
Unique Sensor Testing and Deployment Capability

- Safety Sensor Test Apparatus (SSTA)
  - Metrological performance assessment of hydrogen sensors (laboratory testing)
  - Topical studies / custom applications
  - Support developers, end-users, and R&D with partners in industry, research institutions, and regulatory groups
  - Emerging technologies and markets in support of H2@Scale and the Hubs

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

- Access to the Advanced Research on Integrated Energy Systems (ARIES) facility
  - On-site hydrogen production and utilization resources (available for release studies)
  - Test bed for sensor deployment and release studies

The ARIES facility
Large scale H_2 production and power generation; available for H_2 release studies (commissioned in January 2024).

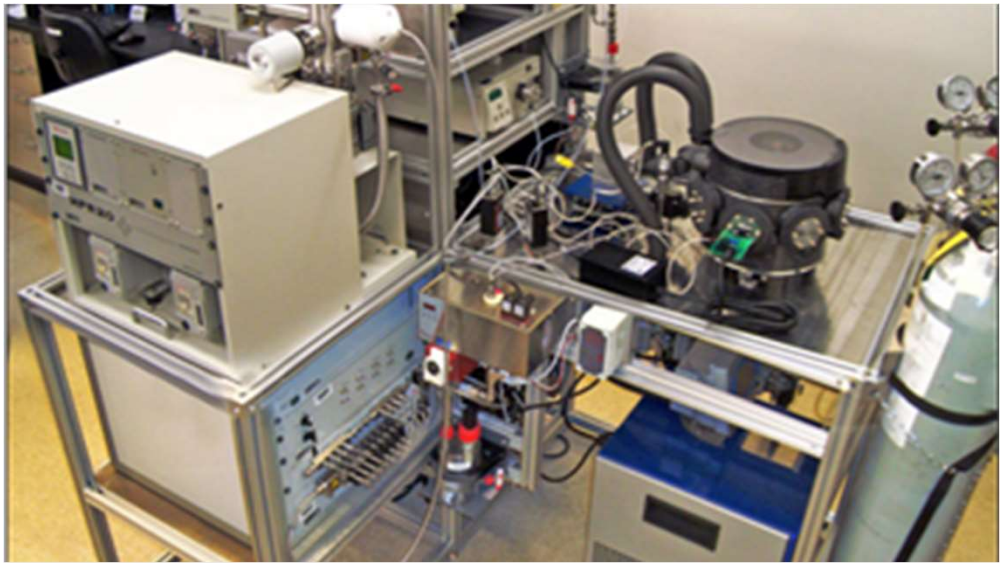
The NREL Sensor Laboratory provides a unique capability to the hydrogen community not otherwise available
Detection Technology Validation, Deployment and Demonstration, Behavior Modeling/Risk Mitigation,and Market Support

NREL Sensor Laboratory
Responding to emerging applications

The NREL Safety Sensor Testing Apparatus (SSTA) was developed to evaluate H_2 safety sensors.

- Upgraded for verifying H_2 sensors down to 15 ppb_v. Low H_2 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*

***Peak Performer 1 RCP** (Reducing Compound Photometer)- H2, CO in Air (910-105)*



The NREL Safety Sensor Testing Apparatus (SSTA)

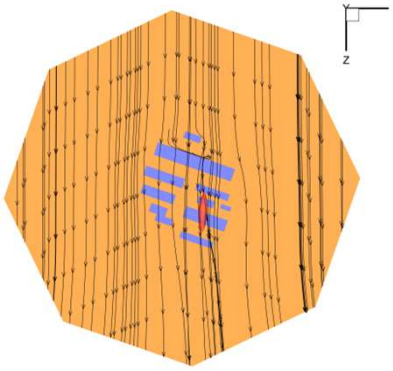
The Sensor Laboratory has testing capability to validate hydrogen sensors with sub-ppm_v detection limits. This provides tools to validate H_2 behavior models and to quantify hydrogen releases within a facility.

ARIES: Testbed for Released Hydrogen Detection and Quantitation

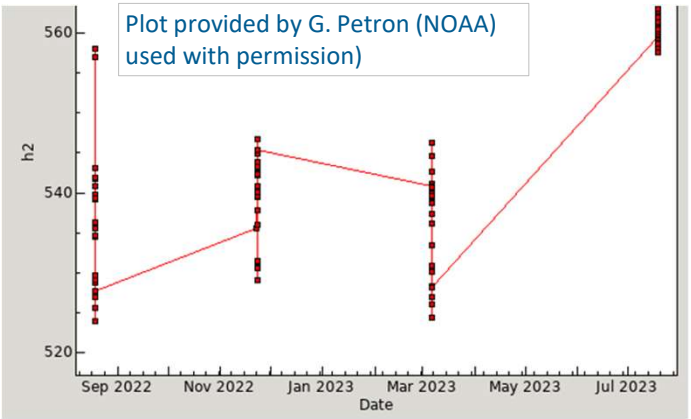
Hydrogen Emissions Monitoring and Quantification

- H_2 releases have potential adverse impacts
  - Detection strategies for NG are not amenable for hydrogen
- 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 HFTO H2@Scale CRADA , EERE Hydrogen Shot FOA , ARPA-E H2 Sense
  - Developed CFD model for H_2 releases at ARIES
    - Guide sensor placement for improved detection and quantitation of releases
  - On-going partnership with NOAA to measure ambient H_2 levels
    - To quantify increased ambient levels of H_2 due to proximal activity
    - To support validation of the NREL-developed CFD dispersion model for H_2 venting at ARIES

ARIES: An NREL testbed to develop, validate, and deploy detection methodologies for facility safety and to quantify releases along the H_2 value chain.



Propagation of hydrogen cloud after leak at 26 mph of wind



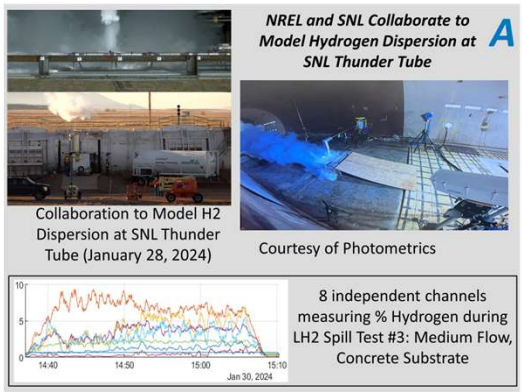
Background H2 Levels at ARIES (performed by NREL & NOAA)

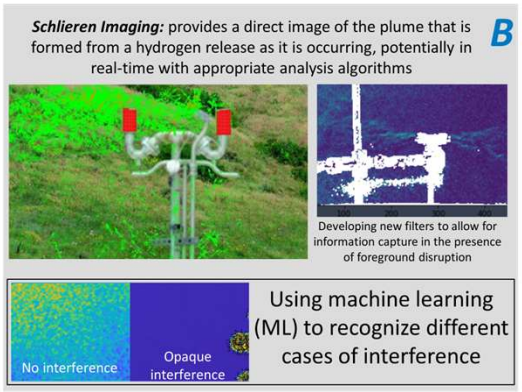
DOE Commitment to Develop Sensors for Hydrogen Releases

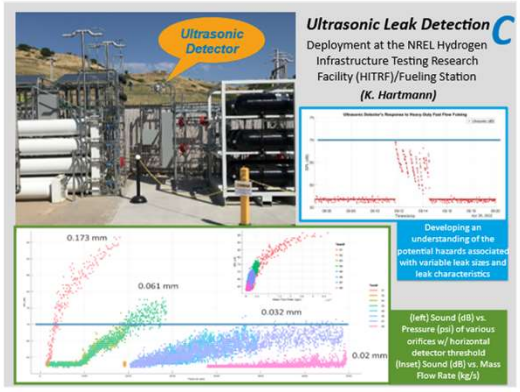
HFTO H2@SCALE CRADA Supporting Advanced Research on Integrated Energy Systems

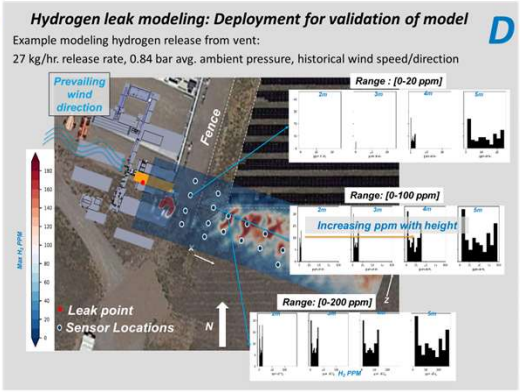
Next Generation Hydrogen Leak Detection--Smart Distributed Monitoring for Unintended H_2 Releases In support of H2@SCALE

- NREL Sensor Laboratory-Led CRADA to implement wide area and standoff hydrogen leak detection for facility safety with NREL HyWAM as the "reference" technology
  - Standoff Methods: Ultrasonic Leak Detection, Imaging Methods (Schlieren),
  - Distributed Sensing Elements: NREL HyWAM, Fiber Optic Detection (with NETL)
  - Non-point sensor use for the fast detection of releases
- CFD modeling for released H2behavior to guide detector placement, identify leak source location, and quantify releases.
- Focus was on safety of hydrogen facilities but may be indicative of pending failures and support hydrogen emissions identification and quantitation.









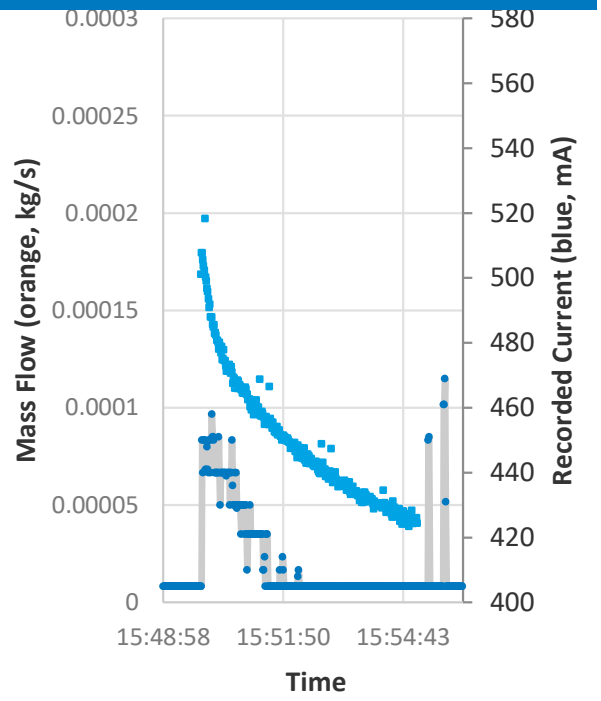
Ultrasonic Leak Detection for H2

Principles

- "Baseline" sounds are recorded to set background levels
- As the gas escapes, it generates sound, some of which is in the ultrasonic range
- The sound pressure level (SPL or dB) is used to identify the presence of a leak
- Hand-held and fixed monitors available

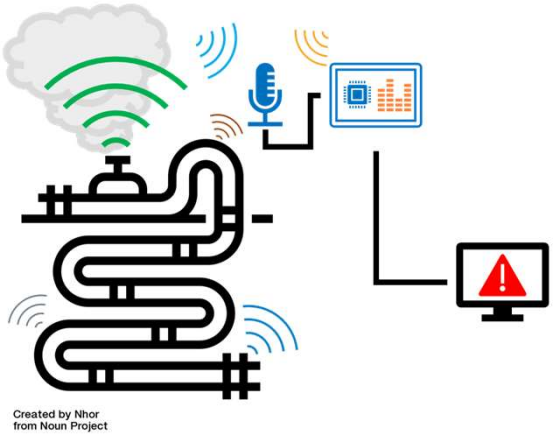
Some detectors go further to estimate the SPL into a leak rate (L/min).

- The calculated rate is dependent on physical parameters, including molecular weight, internal pressure, and angle of detector to the leak
- Leak rate are (currently) rough estimates—semi-quantitative



Analog output of fixed detector 10 meters from the source of H2 release

- At this distance limit of detection is around 0.09 g/s
- Initial Pressure is 54 MPa

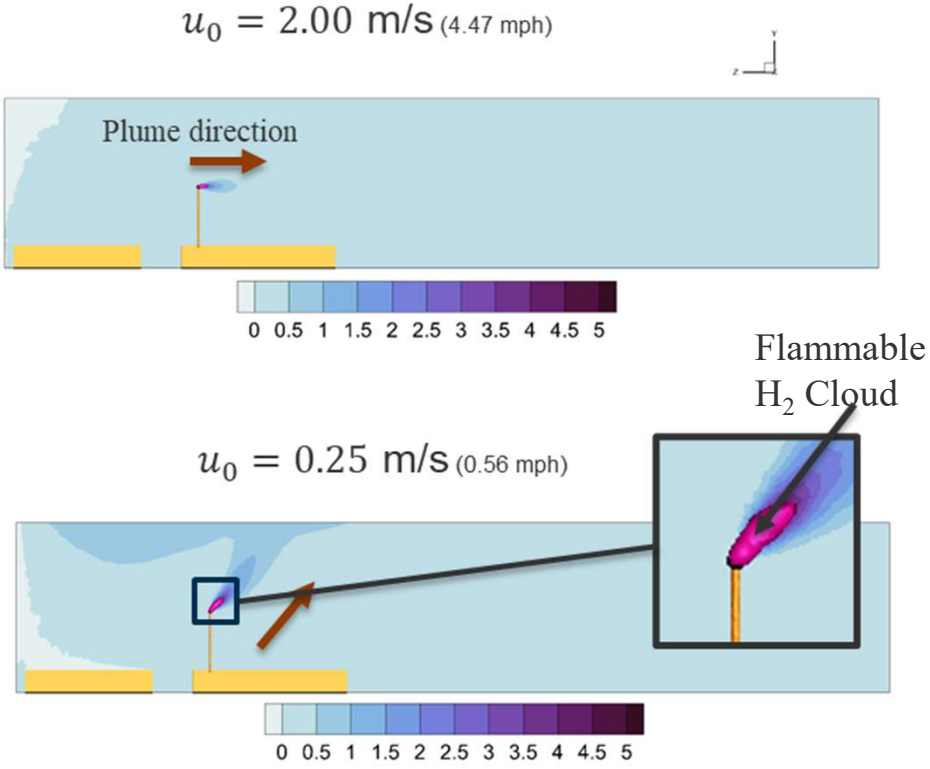


Acoustic array image at 8 m of a He leak of 13.4 L/min

Modelling of H_2 Release Profiles (development of CFD models)

- CFD modeling of H2 releases predicts concentration profiles
  - Validated by empirical (H_2 sensor) data.
  - H_2 dispersion dependent on ambient parameters (wind speed, direction)
  - Inform sensor deployment strategies (detection limits, placement)

- Sensor data and an advanced analytics will inform reverse CFD modeling
  - Release quantitation and source location



See Munjal Shah's Talk "Session 3: Modeling and Measurement"

DOE Commitment to Develop Sensors for Hydrogen Emissions Development of sensors for ppb_v H_2 in Support of the H2 Shot

EERE FOA Number: DE-FOA-0002792

Topic 2: Development and Validation of Sensor Technology for Monitoring and Measuring H2 Losses

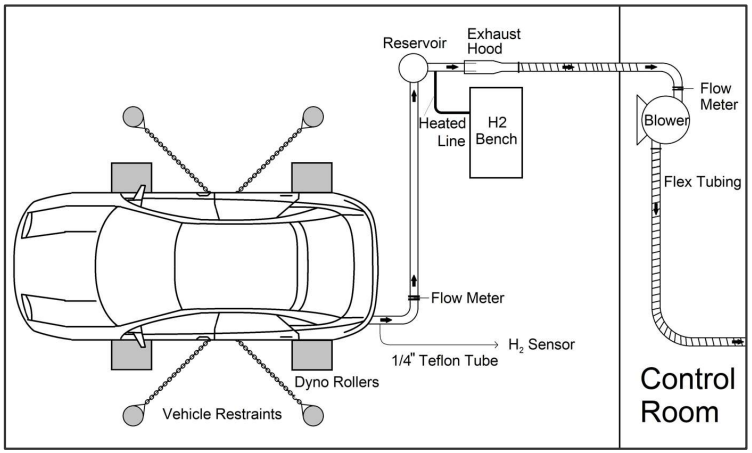
- University- or Industry-led projects to develop H_2 sensors for the "*Development and Validation of Sensor Technology for Monitoring and Measuring H_2 Losses*" Advanced Sensor Designs and Methodologies for H2 Releases for ppb-level H2 detection
  - Specifically strives to provide tools to monitor and quantify hydrogen emissions
  - Multiple Projects wins (6 total); focus on sensors with innovative sensing elements, control circuitry and advanced analytics for exemplary performance metrics
  - Up to 36 months (10/2023 through 9/2026)
  - Goal is to develop detection technology with ppbv level capability for identification of hydrogen emissions and to provide tools for quantitation
- NREL is a formal collaborator on several projects and will provide sensor performance validation, deployment support, and market development
  - Status: Laboratory validation pending, planning for ARIES deployment

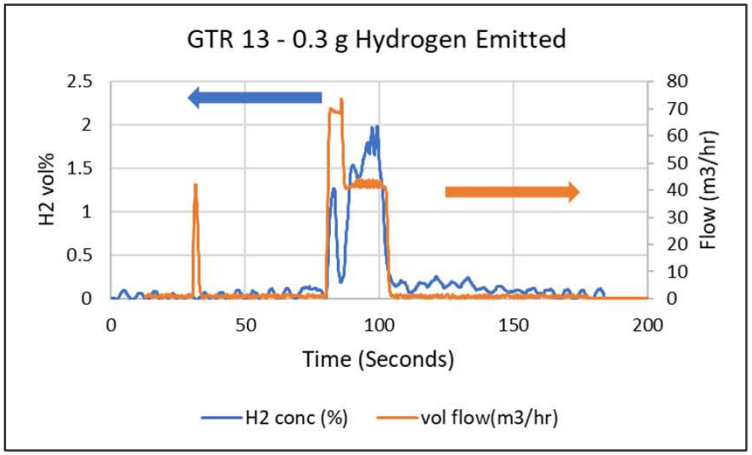
DOE Commitment to Develop Detection for Hydrogen Emissions (Development of methodologies to quantify hydrogen emissions)

ARPA-E FOA Number: DE-FOA-0002784
Topic M: H2Sense

- H2SENSE is to support the development of innovative approaches for hydrogen gas detection and quantification across the hydrogen supply chain. Cost-effective, accurate measurements of hydrogen gas will facilitate detection for discovery and mitigation of emissions to maximize the climate and economic benefits of hydrogen production.
  - NREL collaborated on several proposals, which integrate detection strategies with hydrogen behavior modelling to identify and quantify hydrogen emissions.
  - NREL will support validation and demonstration of detection methodologies for H2 emissions
  - 36-month projects (pending)
- 9 total projects were recently selected (September 12)
  https://arpa-e.energy.gov/technologies/exploratory-topics/H2SENSE

Strategies for quantifying H_2 Emissions (operational) (hydrogen in FC exhaust)





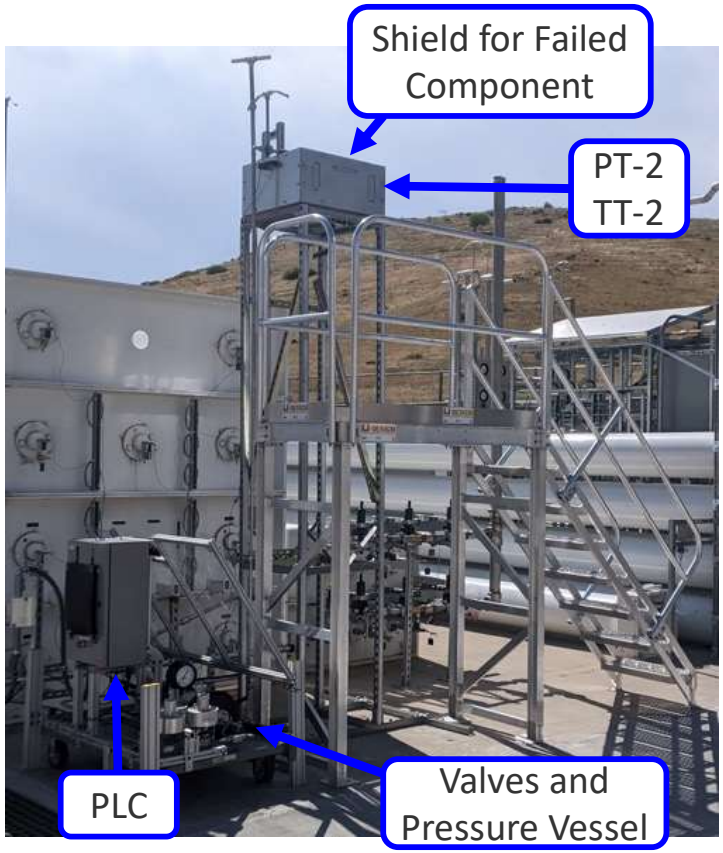
Fuel Cell Electric Vehicle Hydrogen Exhaust Analyzer

- The NREL FCEV Exhaust Analyzer was developed to verify compliance to vehicle safety standards (e.g., GTR 13)
  - A collaboration with Environment and Climate Change Canada (ECCC) and Transport Canada
  - FCEV Exhaust analyzer demonstrated at ECCC on a FCEV using a chassis dynamometer.
- Amenable to stationary fuel cells and other exhaust process (e.g., ICE).
- Not all hydrogen is consumed in FC operation (or ICE)
- Developed for safety assurances, but was adapted for total emissions (with flow monitoring in conjunction with hydrogen detection)

Strategies for H2 Emission (leaks) (Hydrogen losses due to component failure)

The NREL Leak Rate Quantification Apparatus

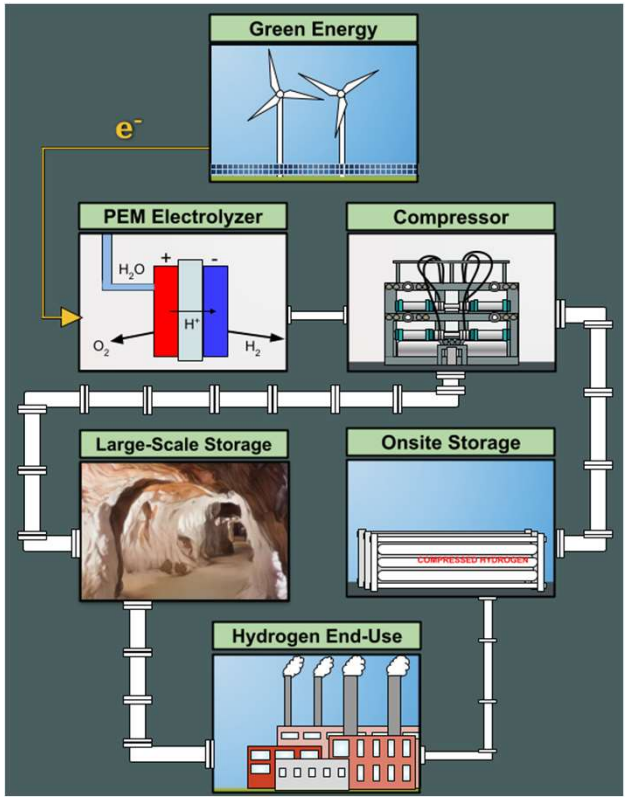
- Developed under the HSR&D Component Reliability R&D program
- Designed to quantify the leak rates (and therefore potential consequences) of failed components under operational conditions.
  - Original focus was on safety
- Failure frequency can provide estimate of losses along value chain, and guide mitigation strategies
- Developing “in-situ” methodologies to quantify hydrogen releases



Diversity, Equity, Inclusion,and Accessibility

Elements for DEIA, Energy and Environmental Justice

- **Clean Hydrogen** is a pathway to decarbonize US and International Energy and Manufacturing Industries
  - H2 is non-toxic and can be handled safely
  - Potential impacts on Global Warming
- **Assurances of Safety is critical for community acceptance**
  - NREL HSR&D supports outreach efforts to community stakeholders to assure that local hydrogen infrastructure can be safe (e.g., emerging large-scale applications)
- **Profitability is critical for industry adoption**
  - Need for equitable distribution
- **Pipeline: Support training of next generation Engineers, Scientists, and Technologist**
  - University collaborations (e.g., UMD, a Capstone project with CU Boulder that includes EJ strategies); Internships
  - BUT: job creation goes beyond university degrees



H2@SCALE and the Hubs represent opportunities for large scale hydrogen but with new challenges

Summary

- **Hydrogen is a critical strategy to decarbonize energy and manufacturing industries**
  - Hydrogen is nontoxic and can be handled safely, but potential for secondary greenhouse impacts
- **Hydrogen releases arise from a variety of mechanisms (process, design features, “leaks”) that contribute to total hydrogen releases**
- **Detection methodologies will be critical to detect and quantify hydrogen emissions.**
  - Detection is to be integrated with advanced analytics (AI) and behavior modelling to effectively identify, quantify, and source locate hydrogen releases
  - Modelling of emissions will contribute to facility safety and reliability
- **DOE is committed to develop the tools to model and mitigate the impact of hydrogen releases**
  - Support modeling to elucidate released hydrogen degradation
  - Support the development of tools for emissions quantitation
  - Support engineering advancements to minimize hydrogen losses along the value chain (including process, design features, and leaks)

The LRQA installed on HITRF

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Thank You

www.nrel.gov

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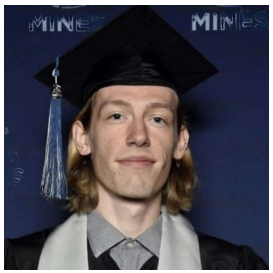

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