THE NREL SENSOR LABORATORY: HYDROGEN LEAK DETECTION FOR LARGE SCALE DEPLOYMENTS

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ABSTRACT
The NREL Hydrogen Sensor Laboratory was commissioned in 2010 as a resource for sensor developers, end-users, and regulatory agencies within the national and international hydrogen community. The Laboratory continues to provide as its core capability the unbiased verification of hydrogen sensor performance to assure sensor availability and their proper use. However, the mission and strategy of the NREL Sensor Laboratory has evolved to meet the needs of the growing hydrogen market. The Sensor Laboratory program has expanded to support research in conventional and alternative detection methods as hydrogen use expands to large-scale markets as envisioned by the DOE National Clean Hydrogen Strategy and Roadmap. Current research encompasses advanced methods of hydrogen leak detection including stand-off and wide area monitoring approaches for large scale and distributed applications. In addition to safety applications, low-level detection strategies to support the potential environmental impacts of hydrogen and hydrogen product losses along the value chain are being explored. Many of these applications utilize detection strategies that supplement and may supplant the use of traditional point sensors. The latest results of the hydrogen detection strategy research at NREL will be presented.

1.0 THE NREL SENSOR LABORATORY

The National Renewable Energy Laboratory (NREL) Sensor Laboratory began in 2008 to support the US Department of Energy (DOE) Hydrogen Safety Codes and Standards subprogram. The previous year, a set of technical targets was made for hydrogen safety sensors (Table 1) by the DOE Office of Energy Efficiency and Renewable Energy (EERE). This set of targets was documented in the Hydrogen, Fuel Cells & Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan [1]. After sensor targets were identified, a goal of 2012 was set to meet these targets and NREL was selected at the National Lab to benchmark the industry.

Table 1. 2007 DOE Table of Targets for Hydrogen Safety Sensors

Targets for Hydrogen Safety Sensor R&D	
Measurement Range	0.1%-10%
Operating Temperature	-30 to 80°C
Response Time	under one second
Accuracy	5% of full scale
Gas Environment	ambient air, 10%-98% relative humidity range

Lifetime	10 years
Interference resistant	e.g., hydrocarbons

1.1 Traditional Focus

With the near-term focus being point sensors, the NREL sensor lab built up capability for characterizing sensors to these DOE targets (Figure 1). Researchers partnered with international labs at the European Union (EU) Joint Research Center (JRC) and Bundesanstalt für Materialforschung und -prüfung (BAM) in Germany to validate test methods [2]. This work led to a workshop in 2011 [3] that identified application dependent pathways to meet targets and a path forward for improvement of sensor performance. After the workshop, the sensor lab continued to work with sensor manufacturers and stakeholders on sensor improvement. The sensor lab also began to further branch out into niche applications and needs such as sensors for crash tests and exhaust measurement.

Figure 1. The NREL Safety Sensor Test Apparatus (SSTA)
Photo by Robert Burgess, NREL 18240

1.2 Expanded Scope of HSR&D

With accumulated expertise in detection and safety applications, researchers expanded the Sensor Lab into the NREL Hydrogen Safety Research and Development (HSR&D) Program. The Sensor Lab remains a key capability of the HSR&D program and is a cornerstone for supplying data to other subprogram tasks. Other safety applications are now included in the scope of the HSR&D

team. The organization of the HSR&D program is outlined in the chart in Figure 2. Much of the additional work focuses on component reliability or applications in which hydrogen detection is an integral part. Around the time of this expansion, the focus of the hydrogen industry began to look toward large-scale deployments and with this larger scope came different detection needs.

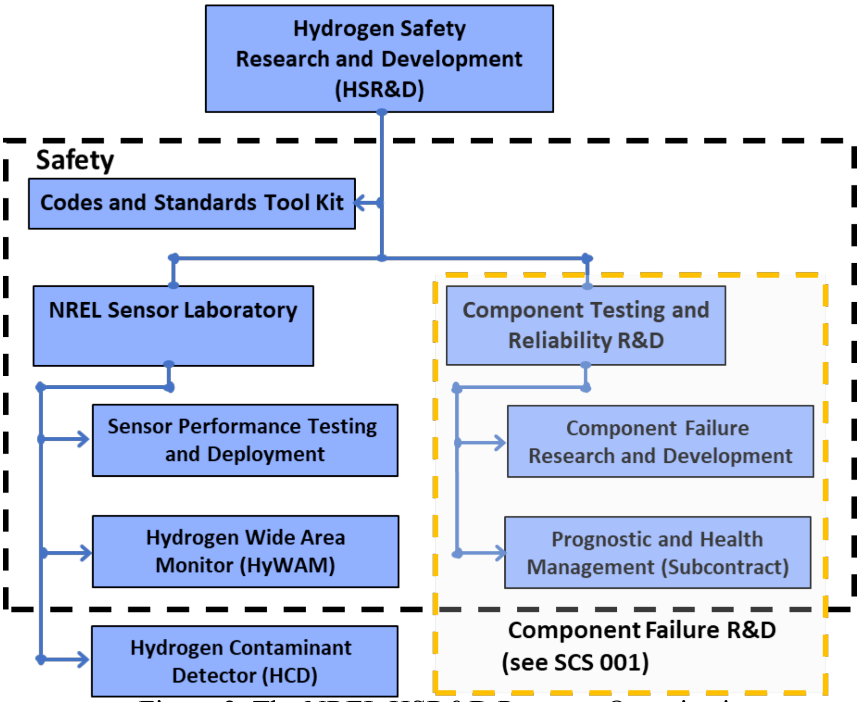

Figure 2. The NREL HSR&D Program Organization

2.0 DETECTION NEEDS

The cost of hydrogen production became the focus of the first hydrogen earthshot outlined by the DOE [4]. The aim of the earthshot is to reduce the cost of clean hydrogen to $1 per 1 kilogram in 1 decade. Increasing scale is a major pathway for reducing production cost. The H2@Scale concept (Figure 3) that had been developed years earlier now has a more important role in the ability to meet this goal. With the focus on hydrogen shifting to larger scale applications [4], advanced and standoff detection methods also became an identified gap. The HSR&D team investigated potential methods to meet these needs following the concepts outlined in H2@Scale.

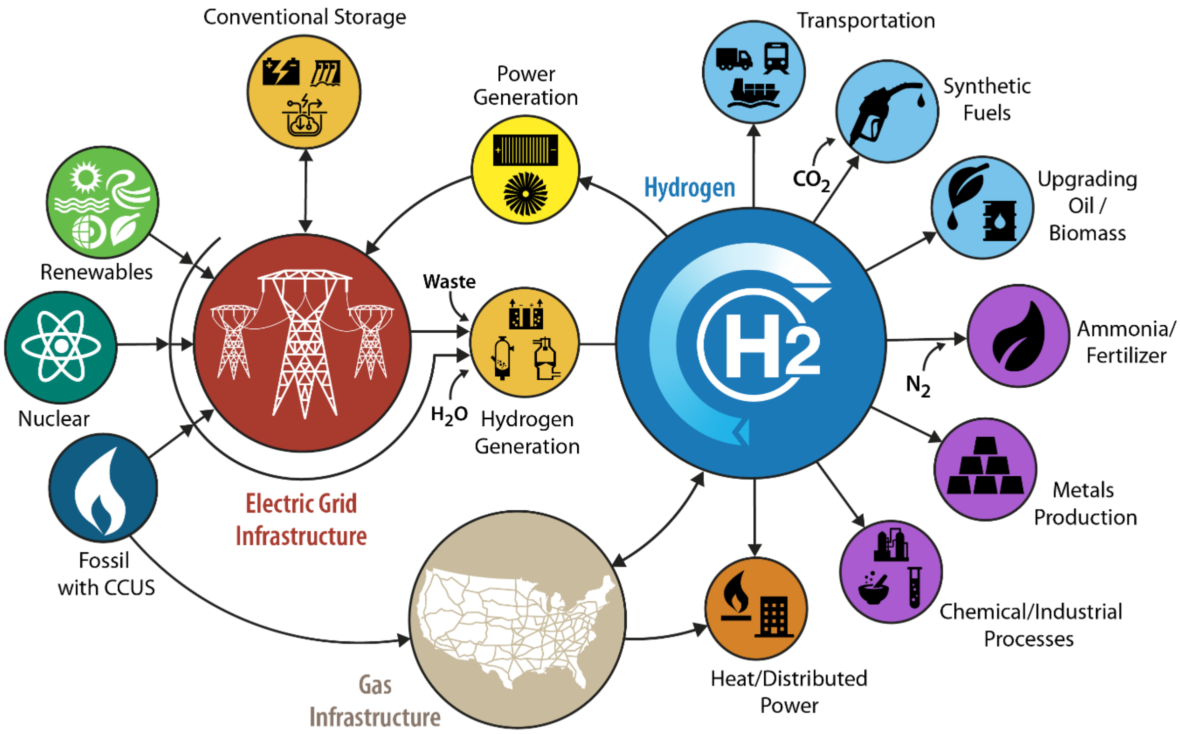

Figure 3. H2@Scale Concept Schematic, NREL 75702

2.1 Point Sensors

Point detection will always be necessary for the safe use of hydrogen and new sensing technologies continue to develop. Point sensors continue to be the best early detection solution for areas where people interact with hydrogen equipment such as dispensers, transfer lines or on-board fuel cell electric vehicles (FCEVs). While many of the DOE targets have been demonstrated, improvement is always possible both for sensor performance and deployment considerations. Niche applications continue to bring further needs for hydrogen sensors with more specific attributes. The NREL Sensor Lab continues to be at the forefront of these advances and is engaged with stakeholders in hydrogen safety (Figure 4).

Figure 4. HSR&D Researchers use the Safety Sensor Test Apparatus (SSTA).
Photo by Werner Slocum, NREL 47022

2.2 Expanded Detection Needs for Large Scale Deployments

Large scale deployments of hydrogen equipment (Figure 5) will involve wider areas and greater volumes of hydrogen being stored. While there has been much experience producing hydrogen for the space and fertilizer industries, bringing hydrogen into a retail setting has further safety considerations. Point detection will be useful in small areas of the production process but may not be practical for large areas or along pipelines. Advanced detection methods will be needed for these deployments that can potentially detect hydrogen or a leak signature using standoff methods that can identify abnormal conditions from a distance.

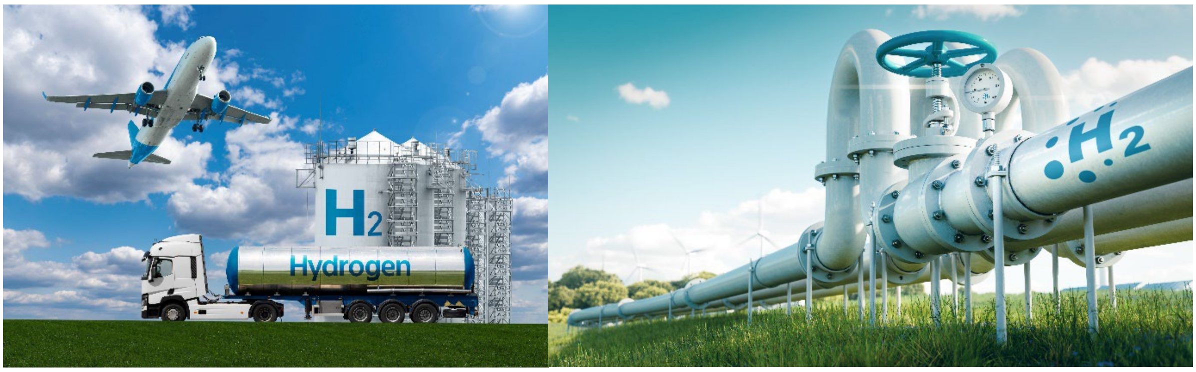

Figure 5. Examples of possible large-scale deployments planned for hydrogen to meet earthshot goals.
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3.0 NREL WORK ON ADVANCED DETECTION METHODS

NREL researchers identified potential detection methods to meet the large-scale deployment requirements. The methods identified show promise in either being able to detect a property of hydrogen from a distance or a signature produced during a leak condition. Planned work in each of these methods will reveal technical benefits and challenges of each detection method. Several of these methods are outlined below.

3.1 Schlieren and Shadowgraph Imaging

Schlieren and Shadowgraph Imaging is the observation of the difference in refractive index in non-homogenous media (i.e., density). Causes of density changes can include temperature, pressure, gas composition, and shock waves. This phenomenon can be observed using camera equipment and digital processing. NREL researchers have recorded an image of a vent stack at the Energy Systems Integration Facility (ESIF) and processed using PIVLab [5] (Figure 6). NREL researchers are investigating the possibility of using this method in real time to identify leaks. While promising, several challenges need to be overcome such as processing speed, focal depth issues, and variability in environmental conditions.

Figure 6. Schlieren and Shadowgraph Image taken at the NREL ESIF.

3.2 Fiber Optic Sensing

Fiber optic sensing is a versatile method for detecting properties surrounding a fiber. Standard fiber optic cable is susceptible to interferences by surrounding pressures, temperatures, and vibrations. These interferences can be translated in real time to determine a signature related to a leak as well as determine its location along the fiber path. This method had been used in natural gas pipeline and has promise for hydrogen pipeline as well.

Other optical methods will add a hydrogen sensitive material to a fiber and monitor the interaction between the material and the surrounding gas mixture. These sensors can be very hydrogen specific and may be able to differentiate among several nodes along a fiber pathway.
Both fiber optic transduction methods are safe as they don't introduce any sparking potential and any electronic equipment can be kept outside of a flammable classified area. They can also be introduced into small spaces such as battery housings to monitor for hydrogen being produced.

3.3 Ultrasonic Leak Detection

Ultrasonic leak detection typically consists of a microphone or piezoelectric sensor to monitor the sound signatures in the surrounding environment. When a leak occurs, the sound signature will listen for the intensity and respond when it gets above a set threshold. This type of sensing is beginning to be common in industrial settings, but has room for improvement. A leak signature (Figure 7) may have a similar intensity to a hailstorm, but a different pattern is observable. NREL is working with manufacturers to identify improvements in detection of these signatures to avoid false positives and increase sensitivity.

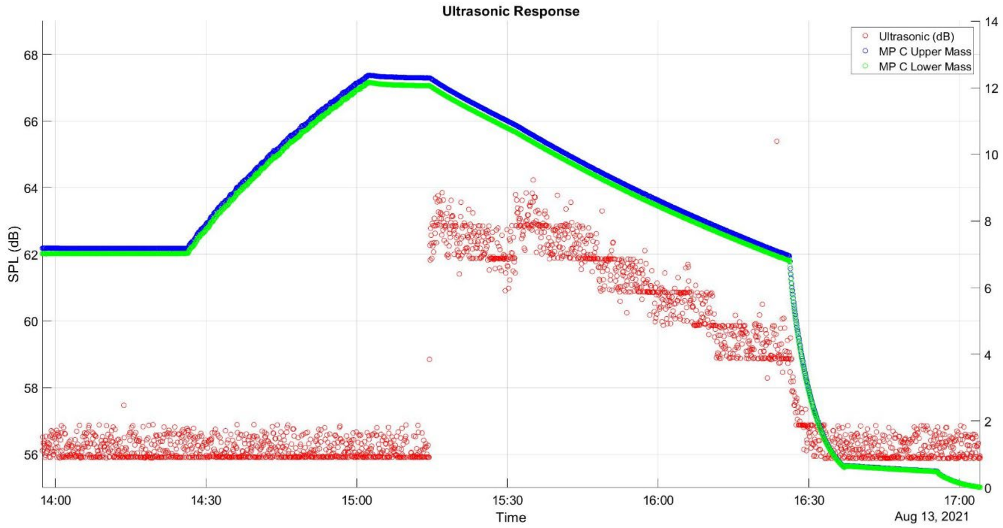

Figure 7. An ultrasonic leak signature observed during a hydrogen leak event.
SPL = Sound Pressure Level, MP C = Medium Pressure Bank C

3.4 Flame Detection and Monitoring

Flame detection is a method for responding to out of normal conditions resulting in hydrogen fires. Hydrogen flames produce the same light as sunlight, so are not visible to human sight in daylight. Flame detectors can observe the wavelengths of light generated by hydrogen flames and produce an electrical signal to take action. While flame detection is commonly used in hydrogen installations, there is still development that needs to be done to increase reliability and acceptance.

Figure 8. A flame detection system installed at NREL ESIF.
Photo by Dennis Schroeder, NREL 40083.

4.0 CONCLUSION

The NREL sensor lab has extensive experience in hydrogen detection starting with point sensors and moving into large scale detection. NREL researchers are investigating advanced detection methods that are currently deployed or have the potential to be deployed in hydrogen installations. NREL has unique capability for deploying sensing technologies including the Hydrogen Infrastructure Testing and Research Facility (HITRF) [7] and the Advanced Research on Integrated Energy Systems

(ARIES) [8] (Figure 9) installations. The NREL HSR&D team are key members in safety and standards groups that have detection needs. The NREL Sensor Lab [9] is available to take on any niche or pending hydrogen detection problems.

Figure 9. The ARIES installation at the NREL Flatirons Campus.
Photo by Josh Bauer / Bryan Bechtold, NREL 73051.

1. Milliken, J. Hydrogen, Fuel Cells and Infrastructure Technologies Program: Multiyear Research, Development and Demonstration Plan. United States: N. p., 2007. Web. doi:10.2172/920934.
2. Buttner, W. et al. Round Robin Testing of Commercial Hydrogen Sensor Performance--Observations and Results: Preprint. N.p., 2010. Print.
3. Buttner, W. et al. Summary and Findings from the NREL/DOE Hydrogen Sensor Workshop (June 8, 2011). N.p., 2012. Print.
4. Hydrogen and Fuel Cell Technologies Office (2023, March 14). Hydrogen Shot. Hydrogen Shot. Retrieved March 27, 2023, from https://www.energy.gov/eere/fuelcells/hydrogen-shot
5. Hydrogen and Fuel Cell Technologies Office (2023, March 14). H2@Scale. H2@Scale. Retrieved March 27, 2023, from https://www.energy.gov/eere/fuelcells/h2scale
6. Thielicke, William, and René Sonntag. "Particle Image Velocimetry for MATLAB: Accuracy and Enhanced Algorithms in PIVlab." Journal of Open Research Software, vol. 9, Ubiquity Press, Ltd., 2021, doi:10.5334/jors.334.
7. National Renewable Energy Laboratory (2017, July 21). Hydrogen Infrastructure Testing and Research Facility. HITRF. Retrieved March 29, 2023, from https://www.nrel.gov/hydrogen/hitrf.html
8. National Renewable Energy Laboratory (2020, August 13). ARIES: Advanced Research on Integrated Energy Systems. ARIES. Retrieved March 29, 2023, from https://www.nrel.gov/aries/
9. National Renewable Energy Laboratory (2011, November 1). *Hydrogen & Fuel Cells*. Safety Sensor Testing Laboratory. Retrieved March 29, 2023, from https://www.nrel.gov/hydrogen/sensor-laboratory.html