VIII.9 NREL Hydrogen Sensor Testing Laboratory

William Buttner (Primary Contact), Ian Bloomfield, Kevin Hartmann, Robert Burgess, Carl Rivkin
National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401-3305
Phone: (303) 275-3903
Email: William.Buttner@nrel.gov

DOE Manager
Will James
Phone: (202) 287-6223
Email: Charles.James@ee.doe.gov

Subcontractor
Element One, Boulder Colorado

Project Start Date: October 1, 2013
Project End Date: Project continuation and direction determined annually by DOE

Overall Objectives

- Quantify performance of commercial hydrogen sensors relative to DOE metrics
- Support development and assess performance of advanced sensor technologies
- Support development and updating of hydrogen sensor codes and standards
- Support infrastructure deployment by providing expert guidance on the use of hydrogen sensors
- Educate the hydrogen community on the proper use of hydrogen sensors

Fiscal Year (FY) 2014 Objectives

- Support Department of Transportation/National Highway Safety Administration (DOT/NHTSA) on the development of the Federal Motor Vehicle Safety Standard (FMVSS) for hydrogen fuel cell vehicles, especially with regards to hydrogen detection requirements identified in the Global Technical Regulation (GTR) for hydrogen-powered vehicles.
- Quantify performance metrics of developmental sensor technologies supported by DOE, including technologies from private organizations and national laboratories.
- Support infrastructure deployment by providing sensor testing capability and guidance to stakeholders.
- Support of NREL component testing and facility upgrades with sensors for both safety and quantitation of hydrogen releases.
- Quantify hydrogen safety sensor requirements for repair facilities
- Coordinate domestic activities in a collaborative European Union (EU)—United States (U.S.) sensor research program, performed in Europe under the auspices of H2Sense [1], which is a European program funded through the Fuel Cell and Hydrogen Joint Undertaking. The EU partners include the Bundesanstalt für Materialforschung und -prüfung (Federal Institute for Materials Research and Testing; BAM, Berlin Germany), the Joint Research Centre (JRC) Institute for Energy and Transport (Petten, the Netherlands), and private companies.

Technical Barriers

This project addresses the following technical barriers identified in the Hydrogen Safety, Codes and Standards section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

(A) Safety Data and Information: Limited Access and Availability

(C) Safety is Not Always Treated as a Continuous Process

(F) Enabling National and International Markets Requires Consistent Regulations, Codes and Standards

(G) Insufficient Technical Data to Revise Standards

(H) Insufficient Synchronization of National Codes and Standards

(K) No Consistent Codification Plan and Process for Synchronization of R&D and Code Development

Contribution to Achievement of DOE Safety, Codes and Standards Milestones

This project will contribute to achievement of the following DOE milestones from the Hydrogen Safety, Codes and Standards section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

- Milestone 2.12: Develop leak detection devices for pipelines. (4Q, 2015)
- Milestone 2.15: Develop holistic design strategies. (4Q, 2017)
- Milestone 2.19: Validate inherently safe design for hydrogen fueling infrastructure. (4Q, 2019)

- Milestone 3.1: Develop, validate, and harmonize test measurement protocols. (4Q, 2014)
- Milestone 4.9: Completion of GTR Phase 2. (1Q, 2017)
- Milestone 5.1: Update safety bibliography and incidents databases. (4Q, 2011-2020)

FY 2014 Accomplishments

- Implemented five formal agreements with industrial partners. The majority of the agreements pertain to use of sensors to facilitate infrastructure deployment, with some support of new advanced sensor technology development.
- Quantified the sensor requirements for preparing existing repair facilities to accommodate hydrogen vehicles.
- Initiated collaboration with DOT/NHTSA to provide technical support pertaining to hydrogen detection requirements specified in the GTR. This activity supports the development of the FMVSS.
- Completed a study quantifying the limitations of using oxygen sensors to quantify hydrogen releases; the results were published in the International Journal of Hydrogen Energy.
- In collaboration with the JRC, completed an initial study quantifying the impact of potential chemical interferences, as identified in the ISO 26140 standard on hydrogen sensors [2], on the major hydrogen sensor platform types. The impact of selected sensor poisons on various platform types was also completed.
- Published the results of an assessment of the impact of miniaturization via micro-machining on hydrogen sensor performance in collaboration with the JRC and the University of Quebec.
- Working with an automotive original equipment manufacturer, initiated the development of an SAE hydrogen sensor evaluation protocol standard or annex for use on-board hydrogen vehicles.

INTRODUCTION

Safety is a major concern for the emerging hydrogen infrastructure. A reliable safety system is comprised of various elements that can include intrinsic design features (e.g., pressure control systems), engineering controls (e.g., sample size minimization), and the use of hydrogen sensors to monitor for releases. Both the International Fire Code (IFC) 2009 and National Fire Protection Association 2 require hydrogen sensors for numerous applications, and accordingly sensors will be mandatory in all jurisdictions that adopt either the IFC or National Fire Protection Association 2. To assure the availability of reliable safety sensors, NREL established the sensor testing laboratory. The NREL sensor test facility provides stakeholders (e.g., sensor developers and manufacturers, end users and code officials) a resource for an independent, unbiased evaluation of hydrogen sensor technologies. Test protocols are guided by the requirements in national and international sensor standards, as well as sensor performance targets established by DOE. In addition to laboratory assessment of sensor performance, a critical mission of the NREL sensor testing laboratory is to educate end users on the proper use of hydrogen sensors. This is achieved, in part, through topical studies designed to illustrate fundamental properties and limitations of various hydrogen sensor technologies, and through outreach activity such as participation on standards development organizations committees and workshops, conference and webinar presentations. The NREL sensor laboratory also facilitates deployment by partnering with end-users to assist in the design and deployment of their sensor system. Within the past year, the NREL sensor laboratory has formalized five agreements with industrial partners, with an emphasis evaluating sensors in support of deployment.

APPROACH

Evaluation of hydrogen safety sensors is an on-going activity at NREL and supports both sensor developers and end-users. The goal of the sensor laboratory is to assure that stakeholders in the hydrogen community have the sensor technology they need. The NREL sensor test apparatus was designed with advanced capabilities, including parallel testing of multiple hydrogen sensors, sub-ambient to elevated temperature, sub-ambient to elevated pressure, active humidity control and accurate control of gas parameters with multiple precision digital mass flow meters operating in parallel. Extended long-term stability testing of sensors is also available. The test apparatus is fully automated for control and monitoring of test parameters and for data acquisition with around-the-clock operation capability. Selected sensors are subjected to an array of tests to quantify the impact of variation of environmental parameters and chemical matrix on performance. Although standard test protocols have been developed [3], these can be adapted for specialized requirements. Results are reported back to the developer or manufacturer to support their future development work[1]. NREL sensor testing also supports end-users by qualifying sensor technology for their application and by educating the hydrogen community on the proper use of hydrogen sensors. The importance of hydrogen safety sensors has been internationally recognized, and the NREL sensor laboratory closely collaborates with international test

[1] It is the policy of the NREL sensor laboratory to treat test results as proprietary, and thus results pertaining to specific clients will not be disclosed without permission.

laboratories, sensor developers, and standards development organizations.

RESULTS

To support hydrogen deployment, the NREL Sensor Test Facility strives to assure the availability of hydrogen sensors to meet stakeholder needs. This is achieved in part by providing an unbiased assessment of performance to sensor developers and manufacturers as well as end users. NREL has also performed numerous topical studies aimed at educating the hydrogen community on the proper use of hydrogen sensors. Results reported here summarize major studies completed in FY 2014 on the characterization and use of hydrogen sensors.

Support of the FMVSS/GTR in collaboration with DOT/NHTSA: Recently the GTR defining safety requirements for hydrogen vehicles was formally implemented. To harmonize international regulations on the safety features of hydrogen vehicles, the GTR is to serve as the basis for the FMVSS in the U.S., which is currently being prepared by NHTSA; prior to formal implementation the draft FMVSS will be open to review and comment by stakeholders. The GTR has several requirements on allowable hydrogen levels external to the vehicle fuel system, including maximum hydrogen in vehicle compartments and allowable maximum hydrogen concentration in tail pipe emissions. Previously, the NREL sensor laboratory worked with DOT/NHTSA to develop a means to verify compliance to the GTR allowable hydrogen concentrations in vehicle compartments following crash tests [4]. The NREL sensor laboratory is expanding its partnership with NHTSA by providing expert advice on sensor technology and to develop analytical methods to verify compliance to the various GTR requirements (e.g., verification of compliance to the GTR tailpipe emission requirement). The NREL sensor laboratory also provides recommendation pertaining to modification of the GTR; for example NREL has recommended removing the GTR explicit endorsement of the use of oxygen sensors to measure hydrogen releases in vehicle compartments. During the Annual Merit Review, the NREL sensor laboratory organized an open meeting with NHTSA and stakeholders including representatives of original equipment manufacturers to review the GTR and the process for developing and implementing the FMVSS.

Hydrogen Safety Sensor Requirements for Vehicle Repair Facilities: The IFC 2009 edition has specific safety requirements pertaining to repair facilities for hydrogen vehicles, including the use of hydrogen detection systems. Thus, existing repair facilities will likely need modifications so as to accommodate hydrogen vehicles, and an integrated design for repair facilities is being explored for this purpose. One aspect of the upgrade will be the use of hydrogen sensors. The NREL sensor laboratory is working with KPA, LLC and Toyota Motor Sales USA on the deployment of a robust hydrogen sensor system as part of the integrated design. In this project, the sensor requirements for use in a repair facility were identified. Several commercial sensor models were identified as potential candidates and are currently being evaluated for long-term stability via an extended 6-month deployment in an actual vehicle repair facility. At the end of the 6-month deployment the overall performance of the candidate sensors will be assessed by the NREL sensor laboratory, and recommendations on the best sensor type for this application will be provided.

International Collaborations (topical studies): Over the past several years, the NREL sensor laboratory has formally collaborated with the sensor test facility at the JRC under the auspices of a Memorandum of Agreement. Under the Memorandum of Agreement, NREL and JRC initiated numerous topical studies aimed at educating the hydrogen community on the proper use of hydrogen sensors. In the past year, the results of several of these topical studies were presented at international conferences and published in the open literature. Included was the publication in the International Journal of Hydrogen Energy of the assessment of the use of oxygen sensors to monitor oxygen displacement as a means to quantify hydrogen releases. Also there is an on-going topical study on the impact of interferants (e.g., a chemical that produce a false positive or negative response on a sensor) and poisons (e.g., a chemical the permanently alters the behavior of a sensor). The results of the interferent testing were presented at the 2013 International Conference on Hydrogen Safety and published in the International Journal of Hydrogen Energy in 2014. Preliminary results on the impact poisons were presented at the 2014 World Hydrogen Energy Conference.

In FY 2014, sensor collaboration expanded to include BAM through an agreement between the Fuel Cell and Hydrogen Joint Undertaking and DOE, which represented the first U.S.-EU project with common objectives. The objectives included:

- To evaluate the capability of current sensors to detect hydrogen and to validate performance through independent laboratory tests.
- To ascertain the needs of facility designers, safety engineers, product designers, etc., with respect to their requirements on how hydrogen sensors should perform in different applications and under which conditions.
- To identify ways to facilitate hydrogen sensor innovation by removing barriers which currently hinder sensor use and commercialization.
- To facilitate the safe use and implementation of hydrogen as an alternative fuel by ensuring correct use of effective hydrogen detection devices.

NREL led the U.S. activity, while the JRC and BAM lead the program in the EU. The EU activity operated under the auspices of H2Sense [1], which was led by BAM and the JRC but included participation by numerous private sensor companies. NREL supported H2Sense as a keynote speaker at the H2Sense Sensor workshop, and through telecoms, program reviews, sensor evaluations, final report (pending), and future work plans.

Sensor Testing and Evaluation: Sensor testing and evaluation remains a core activity within the NREL sensor laboratory, and is performed for customers with both mature as well as developing sensor technology. DOE supported several sensor development programs with private industry and other national laboratories. The NREL sensor laboratory continues to provide the resources necessary to quantify sensor performance. Results of Los Alamos National Laboratory/Lawrence Livermore National Laboratory sensor evaluations were published in the International Journal of Hydrogen Energy. NREL also partnered with two private companies developing sensor technologies with DOE support.

NREL Hydrogen Component Testing Program: The NREL sensor laboratory is an integral element in the NREL component testing program [5,6]. Hydrogen detection is necessary for safety, an indicator for early detection of a pending component failure, and to quantify hydrogen releases. The NREL sensor laboratory has already provided sensors for the pressure relief device testing and performance assessment and calibration of the hydrogen sensors for the hose test [6].

CONCLUSIONS AND FUTURE DIRECTIONS

In the next year, the NREL sensor laboratory will build off its current accomplishment and capabilities via two main avenues—continued evaluation of commercial and developing sensor technologies and support of deployment by expanded collaborations with end users of sensors.

- End-User Support to Support Deployment
  - Guidance on the use of hydrogen sensors in infrastructure deployments, including repair facilities and fueling facilities
  - DOT/NHTSA on the Hydrogen Vehicle FMVSS and compliance to the GTR
  - Sensor performance testing protocol standards for vehicles
  - Barriers to sensor certification and the impact
- Manufacture/Developer Support
  - Commercial and developmental sensor technology performance validation
  - Assessment of wide area monitoring/distributed sensor technology (as a topical study with the JRC)
  - Sensors and analytical methods for the detection of contaminants in hydrogen fuel.

FY 2014 PUBLICATIONS/PRESENTATIONS

Journal Articles and Proceedings Papers

1. "An Assessment on the Quantification of Hydrogen Releases Through Oxygen Displacement Using Oxygen Sensors" W. Buttner, M. Post, R. Burgess, C. Rivkin, L. Boon-Brett, V. Palmisano; in press International Journal of Hydrogen Energy (2014).

2. "Evaluation of Selectivity and Resistance to Poisons of Commercial Hydrogen Sensors", V. Palmisano, L. Boon-Brett, W. Buttner, M. Post, R. Burgess, C. Rivkin, in press International Journal of Hydrogen Energy (2014).

3. "Assessment of Commercial Micro-machined Hydrogen sensors to guide the Next Generation" H. El Matbouly, F. Domingue, V. Palmisano, L. Boon-Brett, M.B. Post, C. Rivkin, R. Burgess, and W.J. Buttner; International Journal of Hydrogen Energy 39 (2014) 4664-4673.

4. "Independent Testing and Validation of Prototype Hydrogen Sensors" Sekhar, Praveen K.; Zhou, Jie; Post, Matthew B.; Woo, Leta**;** Buttner, William J.; Penrose, William R.; Mukundan, Rangachary; Kreller, Cortney R.; Glass, Robert S.; Garzon, Fernando H; Brosha, Eric; International Journal of Hydrogen Energy (2014), 39, 4657-4663.

5. "Selectivity and Resistance to Poisons of Commercial Hydrogen Sensors", E. Weidner, L. Boon-Brett, C. Bonato, F. Harskamp, P. Moretto, M. Post, R. Burgess, C. Rivkin, W.J. Buttner, published in the Proceedings of the World Hydrogen Energy Conference, Seoul, Korea (June 16–19,2014)

Reports

1. "U.S. Hydrogen Sensor Standards and their Impact on Infrastructure Implementation", Kathleen O'Malley, William J. Buttner, H. Lopez, Julie Cairns, Robert Burgess, Carl Rivkin, and Robert Wichert, to be published as an NREL Technical Report (2014).

Presentations

1. "NREL Hydrogen Sensor Testing Laboratory", William Buttner, Carl Rivkin, Robert Burgess, and Ian Bloomfield, DOE Annual Merit Review, June 18th, 2014

2. "NREL Webinar – Hydrogen Component Testing", Robert Burgess, William Buttner, Mike Peters, to be completed Q4 FY2014.

3. "Selectivity and Resistance to Poisons of Commercial Hydrogen Sensors", E. Weidner, L. Boon-Brett, C. Bonato, F. Harskamp, P. Moretto, M. Post, R. Burgess, C. Rivkin, W.J. Buttner, presented at the World Hydrogen Energy Conference, Seoul, Korea (June 16–19, 2014)

4. "An Assessment on the Quantification of Hydrogen Releases Through Oxygen Displacement Using Oxygen Sensors" W. Buttner, M. Post, R. Burgess, C. Rivkin, L. Boon-Brett, V. Palmisano; International Conference on Hydrogen Safety, Belgium (September 9–11, 2013) Belgium.

5. "Evaluation of Selectivity and Resistance to Poisons of Commercial Hydrogen Sensors", V. Palmisano, L. Boon-Brett, W. Buttner, M. Post, R. Burgess, C. Rivkin, International Conference on Hydrogen Safety, Belgium (September 9-11, 2013) Belgium.

6. "Very Low-Cost Visual and Wireless Sensors for Reliable Hydrogen Gas Leak Detection", W. Hoagland, D. Benson, R. Smith, W. Buttner, International Conference on Hydrogen Safety, Belgium (September 9-11, 2013) Belgium.

7. (Invited Talk) "Applications for H2 Sensors—US Practices and Perspective" W. Buttner, C. Rivkin, R. Burgess, I. Bloomfield, H2Sense Hydrogen Sensor Workshop (September 12, 2013) Belgium.

REFERENCES

1. H2Sense, see http://www.h2sense.bam.de/en/home/index.htm, accessed July 30, 2014.

2. "ISO 26142 Hydrogen Detector for Stationary Apparatus"

3. "Standard Hydrogen Test Protocols for the NREL Sensor Testing Laboratory" NREL Brochure (See http://www.nrel.gov/hydrogen/pdfs/53079.pdf, accessed July 30, 2014).

4. "Onboard Hydrogen/Helium Sensors in Support of the Global Technical Regulation: An Assessment of Performance in Fuel Cell Electric Vehicle Crash Tests" M.B Post, R. Burgess, C. Rivkin, W. Buttner, K. O'Malley, and A. Ruiz, NREL Technical Report NREL/TP 5600-56177 (2012) (See http://www.nrel.gov/docs/fy12osti/56177.pdf, assessed July 30, 2014).

5. "Component Standard Research and Development", R. Burgess, A. Kostival, W. Buttner, C. Rivkin, DOE Annual Merit Review (June 18th, 2014), Washington, D.C.

6. "700 Bar Hydrogen Dispenser Hose Reliability Improvement" K. Harrison, H. Dinh, M. Peters, DOE Annual Merit Review (June 17, 2014) Washington, D.C.