VIII.5 NREL Hydrogen Sensor Testing Laboratory

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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 and analyzers
- Educate the hydrogen community on the proper use of hydrogen sensors

Fiscal Year (FY) 2015 Objectives

- Support the Department of Transportation/National Highway Traffic 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 from private organizations and national laboratories, including those supported by DOE as well as privately
- Support infrastructure deployment by providing sensor testing capability and guidance to stakeholders
- Qualify hydrogen safety sensors for specific applications, including those for use in vehicle repair facilities being adapted to accommodate hydrogen vehicles
- Support fuel cell electric vehicle safety through the preparation of a Society of Automotive Engineers (SAE) Technical Information Report (TIR) providing guidance for characterizing on-board hydrogen sensors (J3089, in process)
  - Being developed under the auspices of the SAE Fuel Cell Safety Task Force
- Support of NREL component testing and facility upgrades with sensors for both safety and quantitation of hydrogen releases
- Coordinate international hydrogen safety sensor research and infrastructure deployment through collaboration under the auspices of H2Sense [1], which is a European Union (EU) program funded through the Joint Fuel Cell and Hydrogen Energy (FCH JU)
  - Partners include the Federal Institute for Material Research and Testing (BAM, Berlin, Germany), the Joint Research Centre (JRC) Institute for Energy and Transport (IET, 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 (MYRDD):

(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 & 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 MYRDD:

- 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 2015 Accomplishments

- Implemented or maintained multiple formal agreements with industrial partners, pertaining to the use of sensors in support of infrastructure deployment, on-board vehicle applications, and support of new advanced sensor technology development
- In collaboration with an industrial partner, developed performance requirements for hydrogen sensors used in repair facilities adapted to accommodate fuel cell electric vehicles; developed test protocols to qualify sensors for compliance to the vehicle repair facility requirements, which served as the basis for actual selection of sensors currently being deployed in FCEV repair facilities
- Provide technical support to DOT/NHTSA pertaining to hydrogen detection requirements specified in the GTR
  - Supports the development of the FMVSS
- In collaboration with the JRC, completed an initial study quantifying the impact of potential chemical poisons, identified in the International Organization for Standardization (ISO) 26140 [2] on the major hydrogen sensor platform types
- Working with the SAE Fuel Cell Safety Task Force, completed the first draft of an SAE TIR on hydrogen sensor evaluation protocols for use on board hydrogen vehicles
- Submitted for publication, a book on hydrogen sensors, co-authored with Thomas Hübert/BAM and Lois Boon-Brett/JRC [3]
  - Will be available by the end of 2015

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 (NFPA) 2 require hydrogen sensors for numerous applications, and accordingly sensors will be mandatory in all jurisdictions that adopt either the IFC or NFPA 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 or by the requirements of the application. 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 (SDOs) 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.

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 [4], 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

[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.

sensors has been internationally recognized, and the NREL sensor laboratory closely collaborates with international test laboratories, sensor developers, and SDOs.

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 2015 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 [5]. To harmonize international regulations on the safety features of hydrogen vehicles, the GTR is to serve as the basis for the FMVSS in the United States, 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, including the need to detect hydrogen transients of less than 1 s duration. Recently, the NREL sensor laboratory has identified a hydrogen sensor with a manufacturer specified response time of less than 1 s. This sensor is serving as the basis for the development an analyzer by NREL to verify compliance to FCEV tailpipe exhaust requirements specified in the GTR. This work is also of interest to original equipment manufacturers.

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 has been working with KPA, Ltd. and Toyota Motor Sales USA on the deployment of a robust hydrogen sensor system as part of the integrated design. Test protocols, including both laboratory assessment and field deployment, were developed to qualify commercial sensors for this application. Several sensor model types were tested which led to the identification of acceptable sensors. These sensors are now being deployed in repair facilities that are being modified for FCEV maintenance.

International Collaborations: 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. The sensor collaboration expanded to include BAM through an agreement between FCH JU and DOE, which represented the first US-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 United States 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.

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. The NREL sensor laboratory continues to provide the resources necessary to quantify sensor performance in support of end users. Customers include both infrastructure and vehicle applications.

NREL Hydrogen Component Testing Program: The NREL sensor laboratory is an integral element in the NREL component testing program [6,7]. 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 PRD 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, including the development of tools necessary to verify compliance
  - 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 2015 PUBLICATIONS/PRESENTATIONS

Journal Articles and Proceedings Papers

1. "An assessment on the quantification of hydrogen releases through oxygen displacement using oxygen sensors," Buttner, W.J.; Burgess, R.; Rivkin, C.; Post, M.B.; Boon-Brett, L.; Palmisano, V.; Moretto, P.; International Journal of Hydrogen Energy, volume 39 issue 35, 3 December 2014, 20484-20490.

2. "Evaluation of selectivity of commercial hydrogen sensors," Palmisano, V.; Boon-Brett, L.; Bonato, C.; Harskamp, F.; Buttner, W.J.; Post, M.B.; Burgess, R.; Rivkin, C.; International Journal of Hydrogen Energy 39 issue 35, 3 December 2014, 20491-20496.

3. "Selectivity and resistance to poisons of commercial hydrogen sensors," Palmisano, V.; Weidner, E.; Boon-Brett, L.; Bonato, C.; Harskamp, F.; Moretto, P.; Post, M.B.; Burgess, R.; Rivkin, C.; Buttner, W.J.; International Journal of Hydrogen Energy (2015).

4. Accepted for publication in the proceedings of the Sixth International Conference on Hydrogen Safety (October 19-21), Yokohama, Japan:

5. "Hydrogen Monitoring Requirements in the Global Technical Regulation on Hydrogen and Fuel Cell Vehicles," William Buttner, Carl Rivkin, Robert Burgess, Kevin Hartmann, Ian Bloomfield, Matt Post, Lois Boon-Brett, Eveline Weidner (in press).

6. "Overview of the DOE Hydrogen Safety, Codes and Standards Program--Part 4: Hydrogen Sensors," W.J. Buttner, C. Rivkin, R. Burgess Eric Brosha, Rangachary Mukundan, Will James, Jay Keller (in press).

Reports

1. "An Overview of North American Hydrogen Sensor Standards," K. O'Malley, H. Lopez, R. Wichert, J. Cairns, W.J. Buttner, NREL Technical Report NREL/TP-5400-62062 (2015) in press.

2. (Contributor) International Energy Agency Hydrogen Implementing Agreement Task 31 Hydrogen Safety Final Technical Report W. Hoagland (November 2014).

3. "Hydrogen Technologies Safety Guide," C. Rivkin, R. Burgess, W. Buttner, NREL Technical Report (January 2015), NREL/TP-5400-60948.

Book

1. "Sensors for Safety and Process Control in Hydrogen Technologies," Thomas Hübert, Lois Boon-Brett, William Buttner, CRC Press (2015) in-press.

Presentations

1. "Hydrogen Sensors," W. Buttner, C. Rivkin, R. Burgess, L. Boon-Brett, E. Weidner, T. Hűbert, HySafe Research Priorities Workshop, (November 11-12, 2014), Washington, DC.

2. "Hydrogen Component Testing," C. Rivkin, C. Ainscough, R. Burgess, W. Buttner, M. Peters, H. Dinh, NREL WEBINAR (Feb 4, 2015).

3. "Hydrogen Detectors, Applications and Performance--The NREL Sensor Laboratory," W. Buttner, C. Rivkin, R. Burgess, K. Hartmann, M. Bubar, I. Bloomfield, Hydrogen Safety Panel, Sacramento, CA (March 4, 2015).

4. "H2 Detection and H2 Sensors," P. Moretto, E. Weidner, W. Buttner, IEA-HIA Task 37 Experts Meeting, Karlsruhe, Germany (April 20-22, 2015).

5. "Sensor Testing Lab Overview," W. Buttner, C. Rivkin, R. Burgess, K. Hartmann, M. Bubar, I. Bloomfield, presented to DOE Hydrogen Codes and Standards Tech Team Telecom Meeting (May 14, 2015).

6. "Hydrogen Sensors--Fuel Systems Application," W. Buttner, NREL Component Research Open House (May 28, 2015).

7. "NREL Hydrogen Sensor--Testing Laboratory," W. Buttner, C. Rivkin, R. Burgess, K. Hartmann, M. Bubar, I. Bloomfield, U.S. Department of Energy Hydrogen and Fuel Cell Program Annual Merit Review and Peer Evaluation (June 6-10, 2015) Washington, D.C.

8. To be Presented at the Sixth International Conference on Hydrogen Safety (October 19-21) Yokohama, Japan:

9. "Hydrogen Monitoring Requirements in the Global Technical Regulation on Hydrogen and Fuel Cell Vehicles," William Buttner, Carl Rivkin, Robert Burgess, Kevin Hartmann, Ian Bloomfield, Matt Post, Lois Boon-Brett, Eveline Weidner.

10. "Overview of the DOE Hydrogen Safety, Codes and Standards Program--Part 4: Hydrogen Sensors," W.J. Buttner, C. Rivkin, R. Burgess, Eric Brosha, Rangachary Mukundan, Will James, Jay Keller.

11. "Impact of Environmental Parameters on Hydrogen Safety Sensor Performance," William Buttner, Carl Rivkin, Robert Burgess, Kevin Hartmann, Eveline Weidner, Valerio Palmisano, Christian Bonato.

REFERENCES

1. H2Sense, see http://www.h2sense.bam.de/en/home/index.htm, accessed July 30, 2015.

2. "ISO 26142 Hydrogen Detector for Stationary Apparatus."

3. "Sensors for Safety and Process Control" T. Hűbert, W. Buttner, L. Boon-Brett, CRC Press (2015) in press.

4. "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).

5. Addendum 13: Global technical regulation No. 13 Global Technical Regulation on hydrogen and fuel cell vehicles ECE/TRANS/180/Add.13, July 19, 2013) (see: http://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29wgs/wp29gen/wp29registry/ECE-TRANS-180a13e.pdf, accessed July 30, 2015).

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

7. "700 Bar Hydrogen Dispenser Hose Reliability Improvement," K. Harrison, H. Dinh, M. Peters, DOE Annual Merit Review (June 17, 2014) ,Washington, DC.