IX.2 Hydrogen Safety Sensors

Robert Burgess (Primary Contact), William Buttner, Matthew Post
National Renewable Energy Laboratory (NREL)
1617 Cole Boulevard
Golden, CO 80401
Phone: (303) 275-3823; Fax: (303) 275-2905
E-mail: robert.burgess@nrel.gov

DOE Technology Development Manager: Antonio Ruiz
Phone: (202) 586-0729; Fax: (202) 586-2373
E-mail: Antonio.Ruiz@ee.doe.gov

Project Start Date: 2008
Project End Date: 2012 (based on reaching current multi-year research development and demonstration plan, safety sensor performance targets)

Objectives

- Establish testing capabilities to characterize production and near-term development safety sensor performance at mixtures from 0 to 4% hydrogen in air.
- Participate on hydrogen sensor codes and standards development committees.
- Perform testing on hydrogen safety sensors over a range of environmental (e.g., temperature, pressure, relative humidity), chemical (e.g., concentration and composition of interferants) and physical (flow rate, test duration) conditions.
- Develop relationships with manufacturers to facilitate sensor characterization and cultivate the next generation of products capable of meeting DOE performance targets.
- Collaborate with industry and government agencies to develop sensor testing protocols.
- Expand testing capabilities to include 0 to 100% hydrogen concentrations in air.

Technical Barriers

This project addresses the following technical barriers from the Codes and Standards section (3.7.4) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration (RD&D) Plan:

(A) **Limited Government Influence on Model Codes** – The code development process is voluntary, so the government can affect its progression, but ultimately it is up to the code development organizations (CDOs).

(B) **Competition among SDOs and CDOs** – The competition between various organizations hinders the creation of consistent hydrogen codes and standards.

(C) **Limited State Funds for New Codes** – Budget shortfalls in many states and local jurisdictions impact the adoption of codes and standards because they do not always have the funds for purchasing new codes or for training building and fire officials.

(F) **Limited DOE Role in the Development of International Standards** – Governments can participate and influence the development of codes and standards, but they cannot direct the development of international standards.

(G) **Inadequate Representation at International Forums** – Participation in international forums and meetings is voluntary and, to date, has been limited by budgetary constraints.

(H) **International Competitiveness** – Economic competition complicates the development of international standards.

(I) **Conflicts between Domestic and International Standards** – National positions can complicate the harmonization of domestic and international standards.

(J) **Lack of National Consensus on Codes and Standards** – Competitive issues hinder consensus.

(K) **Lack of Sustained Domestic Industry Support at International Technical Committees** – Cost, time and availability of domestic hydrogen experts have limited consistent support of the activities conducted within the international technical committees.

(N) **Insufficient Technical Data to Revise Standards** – Research activities are underway to develop and verify the technical data needed to support codes and standards development, retrofitting existing infrastructure and universal parking certification, but are not yet completed.

Contribution to Achievement of DOE Safety, Codes & Standards Milestones

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

- **Milestone 18**: Implement research program to support new technical committees for the key standards including fueling interface and fuel storage. (4Q 2007)

- **Milestone 20**: Draft standards for hydrogen detectors in stationary applications (UL). (4Q, 2008)
- **Milestone 21**: Completion of necessary codes and standards needed for the early commercialization and market entry of hydrogen energy technologies. (4Q, 2012)

Accomplishments

- Market definition activities have identified over 120 sensor products to date.
- Test protocols developed to insure reproducible and repeatable testing methodologies.
- Design of new NREL testing chamber and supporting systems. Will provide extended capability and control of operating parameters. Test chamber operational by late Fiscal Year 2009.
- Published sensor lab fact sheet and set up Web-based communication tool for improved flow of time sensitive information.
- Developed collaborations with key stakeholders.

Introduction

Current codes and standards require the use of gas detection for hydrogen installations (example: National Fire Protection Association 52). From response to these requirements, it has become evident that current hydrogen safety sensor products do not always meet the needs of end-users. In April of 2007, a DOE-sponsored hydrogen sensor workshop was held to define end-user needs and formulate these needs into a set of targets for sensor performance. NREL has been tasked with expediting sensor market development in order to meet the DOE multi-year RD&D targets set for 2012.

Approach

By developing standard test methods and measuring sensor performance of a wide range of sensors of different designs and from a many different manufacturers, NREL will characterize the sensor market and identify gaps relative to the DOE targets. With this information we will be able to work closely with sensor manufacturers so that they can better understand the performance of their sensor relative to the needs of hydrogen stationary applications. This work will be directed toward sensor research and development, such that sensor manufacturers, utilizing the resources of a national lab, can expedite their product development life cycle.

In addition, the sensor market expertise gained will be used to support commercialization through development of representative codes and standards for safety sensor certification. Commercialization support will include collaboration with key stakeholders as well as direct participation on the relevant codes and standards committees.

Results

DOE has published performance targets for hydrogen safety sensors in the multi-year RD&D plan (see Table 1). NREL's is working toward characterization of sensor performance relative to the DOE targets by testing commercially available sensors and near-term developmental sensors. Through research on the sensor market, over 120 different sensor technologies have been identified. Information on each of these designs is being compiled in spreadsheet format. This data resource includes manufacturer information, product specifications, contact lists and links to communication logs and test data. The spreadsheet is only available internally. For external communication, manufacturers have access to a Web-based data storage system with password protection. This allows for efficient and secure downloading of manufacturer proprietary data and transfer of larger data files. This Web-based information exchange will also be used for transmitting summary reporting on the sensor testing effort.

NREL is developing standardized test protocols for repeatability and reproducibility of the sensor data. Tests are automated using a LABview data acquisition system. Instrumentation is calibrated with traceability to National Institute of Standards and Technology (NIST) standards. The tests being run are based on emerging standards for safety sensor certification. As an example of the data that is being collected, Figures 1 and 2 show the results of a sample linearity test. This test is run by varying hydrogen gas concentration in air from 0 to 2%. Gas concentration is stepwise increased, recording

TABLE 1. DOE Multi-Year RD&D Targets

Table 3.7.2. 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)

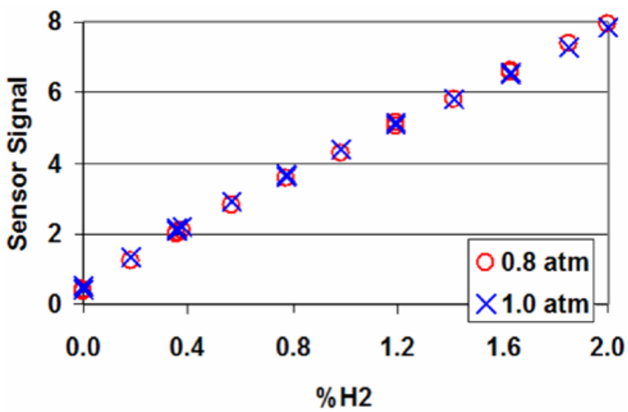

FIGURE 1. Sample Sensor Data, 0 to 2% Hydrogen in Air

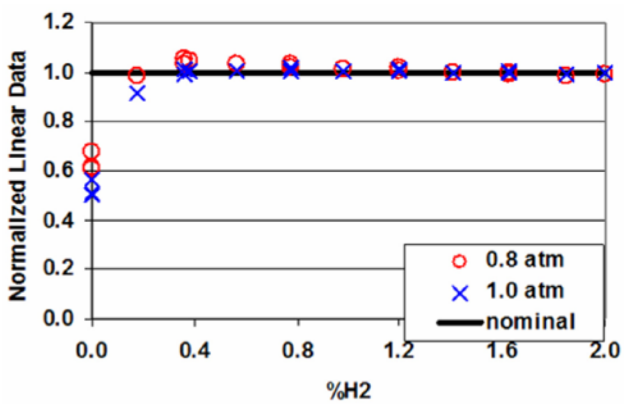

FIGURE 2. Normalized Hydrogen Sensor Data, 0 to 2% Hydrogen in Air

sensor response at each hold point. Comparing this data to the Table 1 DOE target for measurement range, data show a nonlinear effect near the lower detection limit of 0.1%. This nonlinear effect is most evident on the normalized data plot in Figure 2. Note that the nonlinear sensor response below 0.1% is not necessarily an indication of the lower detection limit. The sensor is continuing to produce a measurable signal that can be corrected through signal processing methods. There is additionally a higher test data variance below 0.1% which would result in degradation in data accuracy.

NREL is in the process of designing and building a new custom test apparatus which will expand the range of environmental condition that the sensors are exposed to. Figure 3 shows the test apparatus during assembly and system check-out testing. The apparatus will be fully operational toward the end of FY 2009. Additional capabilities include a wider temperature range, wider humidity range, vacuum capability and increased number of feed through ports so that an increased number of sensors can be tested concurrently.

For better communication of test project objectives, a sensor lab fact sheet was published and is available online at www.nrel.gov/hydrogen/pdfs/42987.pdf. There have been several instances where manufacturers have found the fact sheet information online and subsequently contacted NREL to participate in the sensor testing project. In addition to the Web-based communication, NREL is also extending collaboration with national and international organizations working in the area of sensor research and development. This includes codes and standards development organizations such as Underwriters Laboratory (UL) and International Organization for Standardization (ISO) (standards for safety sensor testing include UL2075 and ISO 26142). NREL is collaborating with researchers at NIST's Building and Fire Research Lab working in the area of hydrogen safety sensors. Additionally, the European Commission is supporting hydrogen safety sensor technology with similar program objectives to the DOE/NREL effort. This has resulted in collaboration with the European Commission laboratory Joint Research Centre in Petten Netherlands.

FIGURE 3. NREL's Sensor Test Apparatus

Properly deploying sensors will also require understanding of hydrogen cloud dispersion dynamics thereby insuring sensor installations will accurately detect a hydrogen leak. NREL has recently completed a computational fluid dynamics (CFD) study and test validation of hydrogen gas dispersion in a residential garage. Utilizing this validated model, we can analyze leak scenarios in supporting codes and standards development and also for analyzing specific applications.

Conclusions and Future Directions

NREL will continue supporting the development of improved hydrogen safety sensor products by:

- Working closely with hydrogen safety sensor manufacturers to improve performance, with particular attention to enabling technologies.
- Supporting hydrogen sensor codes and standards development by direct support of codes and standards development organizations.
- Expanding the work on testing protocols through collaboration with key stakeholders.
- Performing a wider range of environmental tests utilizing new NREL test apparatus.
- Integrating CFD leak scenario analysis with sensor project to validate sensor placement.

FY 2009 Publications/Presentations

1. "Test protocol document, hydrogen safety sensor testing. Phase I, Non-flammable mixtures", R. Burgess, C. Blake, and C. Tracy, NREL/TP-560-42666, NREL Peer reviewed paper.

2. "Low Power MEMS Thermal Conductivity Sensors for H2 [with discussion of Analog Electronics and Applications]", B. Balakisnan, W. Buttner, M. Findlay, G. Maclay, J. Stetter, and A. Kelsch, 12th International Meeting on Chemical Sensors, July 2008.

3. "Development and Compliance to Hydrogen Sensor Codes and Standards, The NREL Hydrogen Sensor Testing Laboratory", R. Burgess et al., NHA Hydrogen Conference, March 2009.

4. "An Overview of Hydrogen Safety Sensors and Requirements", Buttner et al., 3rd International Conference on Hydrogen Safety (ICHS), to be presented, September 2009.