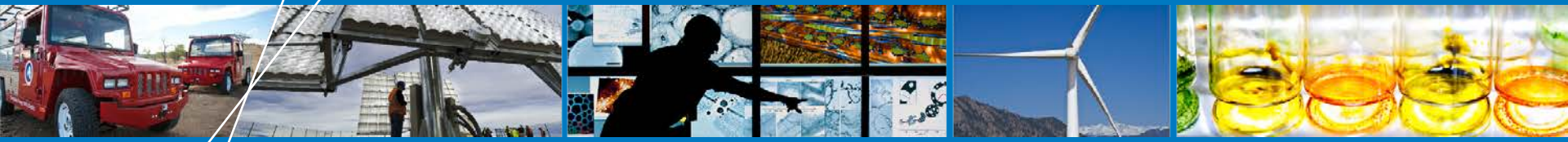
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Component Standard Research & Development



2012 DOE Annual Merit Review

Robert Burgess , William Buttner, Matthew Post, Carl Rivkin, Chad Blake

National Renewable Energy Laboratory

May 15, 2012

Project ID # SCS-002

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Overview

TIMELINE

- Start date: April 2007
- Project end date: Multi-year DOE RD&D program plan

BARRIERS

2012 Multiyear RD&D Barriers

- ***Consensus*** – H. "Insufficient synchronization of national codes and standards", F. "Enabling national and international markets requires consistent RCS"
- ***Technology Readiness*** – G. "Insufficient technical data to revise standards", K. "No consistent codification plan and process for synchronization of R&D and code development"

BUDGET

- Funding for FY11: **$750K**
- Planned funding FY12: **$500K**

PARTNERS

- Industry (component manufacturers, automotive OEMs, gas suppliers)
- Laboratories/universities (LLNL, LANL, ORNL, JRC, BAM, NHTSA, NIST, NASA, Battelle, Powertech, JARI, IIT, IEEE, others)
- Codes & standards development organizations (SAE, CSA, ASME, ISO, UL, NFPA, IEC, GTR, ANSI, others)

Outline: Component Standards R&D

- **NREL's Hydrogen Sensor Testing Lab**
  - Sensor R&D support for commercialization and deployment
  - Leveraged results through partnership and collaboration
  - Focused on 2015 infrastructure requirements (including dispensing stations, repair garages, parking structures and residential application)
- **Hydrogen Component Standards R&D**
  - Support of developing hydrogen component standards: SAE, CSA, ASME, NFPA, UL, ISO
  - Prioritization and implementation of R&D testing and support activities

Sensor Testing Laboratory

NREL Sensor Testing Lab Relevance

- Presidential Budget Request for FY2013 -

Safety, Codes & Standards — Efforts will include development of technologies such as hydrogen sensors, including advanced design and fabrication to ensure safety, performance, and reliability of an integrated sensor. Safety, Codes & Standards efforts will also be coordinated with other technology development activities to develop requirements (for design, performance, and qualification) and test methods for various components and systems.

Energy Efficiency and Renewable Energy/
Hydrogen and Fuel Cell Technologies/
Emerging Technologies

FY 2013 Congressional Budget

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NREL Sensor Testing Lab Approach

- Provide independent assessment of hydrogen sensor performance
- Interact with manufacturers to meet application-specific sensor performance targets as defined at the 2011 DOE-NREL H2 Sensor Workshop
- Support hydrogen sensor codes & standards development (national and international)
- Test/validate emerging sensor technologies
- Foster collaboration between industry and government agencies for sensor testing validation
- Support end users with information on sensor performance

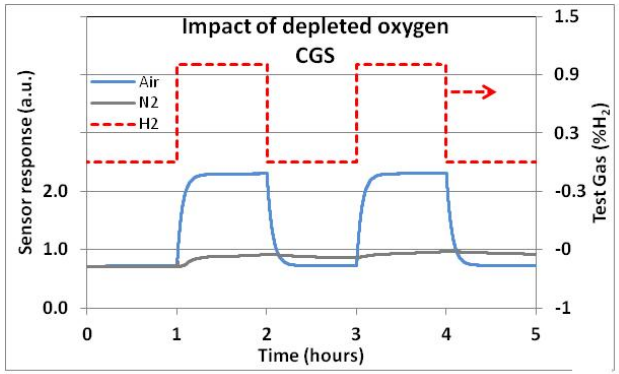
The ultimate goal of the Hydrogen Sensor Testing Laboratory is to ensure that end users get the sensing technology they need

Oxygen Dependence Results

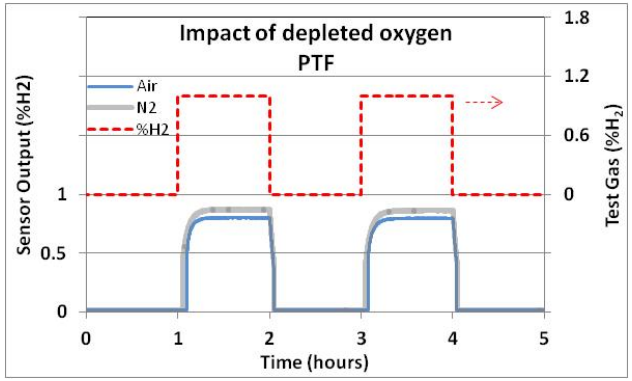
Purpose: ***To provide sensor guidance for applications using hydrogen sensors in reduced oxygen environments***

Results:

- CGS, TC, and PTF
  - Leveraged results under MOA with JRC
  - Presented at 2011 ICHS
  - Submitted to IJHE, in press



- EC, MOS, MOX
  - In preparation for IJHE
  - Represents major hydrogen point sensor platform types

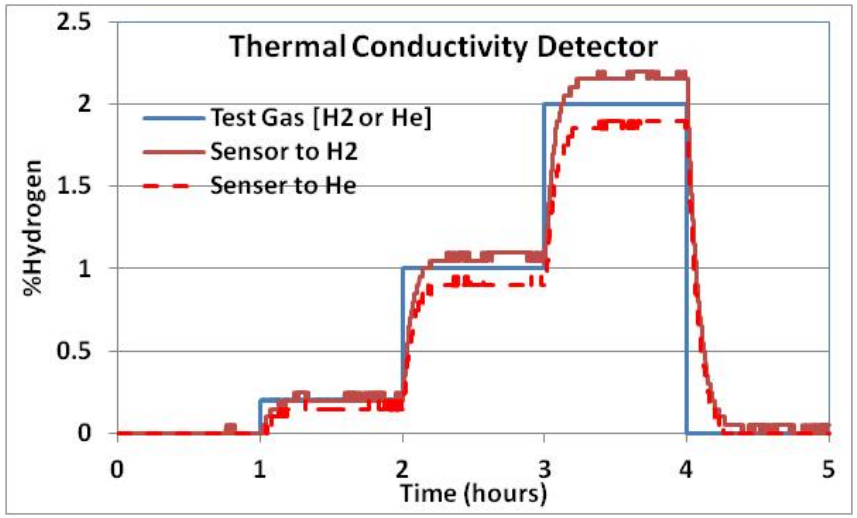


To educate end-users on the proper use of hydrogen sensors

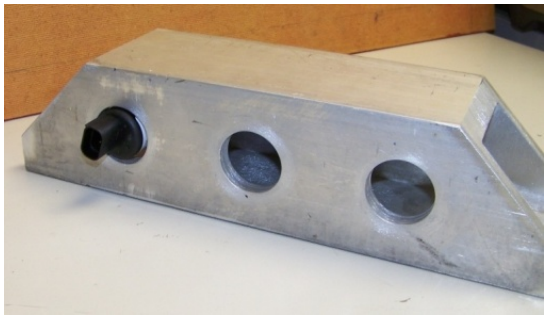
Vehicle Crash Test Field Deployment Results

Purpose: ***To provide NHTSA/DOT with safety sensor guidance for use in FMVSS crash tests***

- Critical component of the UN GTR FCV safety requirements
- Selection of TCD (thermal conductivity detector)
  - Responsive to helium and hydrogen
  - Specific model selected for survivability in harsh vibration and shock environment
- Survivability verified in DOT crash tests
  - Calibrated and tested for He
  - Frontal impact (3 out of 3 sensors survived)
  - Side impact (3 out of 3 sensors survived)
  - Side pole impact (3 out of 3 sensors survived)
  - Completed April FCV testing



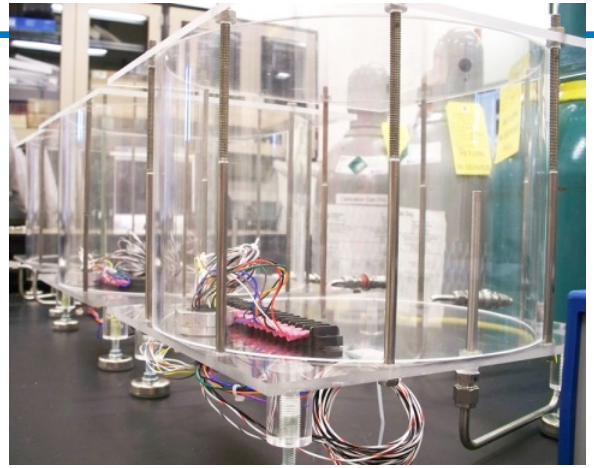
Response characteristics in helium and hydrogen



Mounting bracket for on-board installation of TCD device

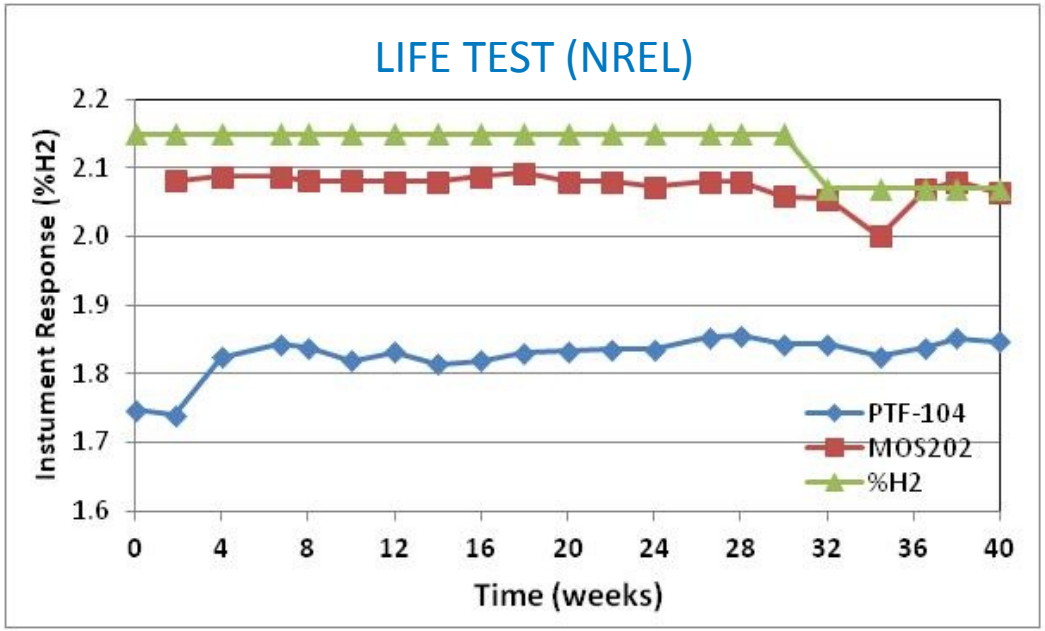
Long Term Exposure Results

Purpose: ***To determine long-term sensor stability mimicking real world deployment scenarios***



Life test fixture

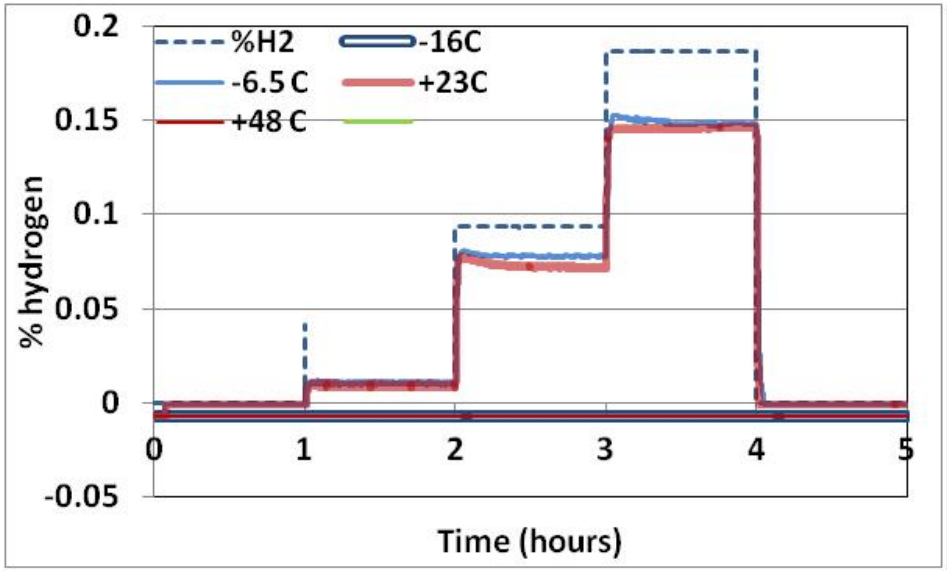
The sensors are stored in clean air at laboratory ambient T and P in a controlled humidity (45% ± 2% RH) enclosure and challenged every two weeks to 2.0% ± 0.2% hydrogen. MOS and PTF results are shown for a 40 week time scale. The test is on-going. Additional technologies are being subjected to the life test protocol.



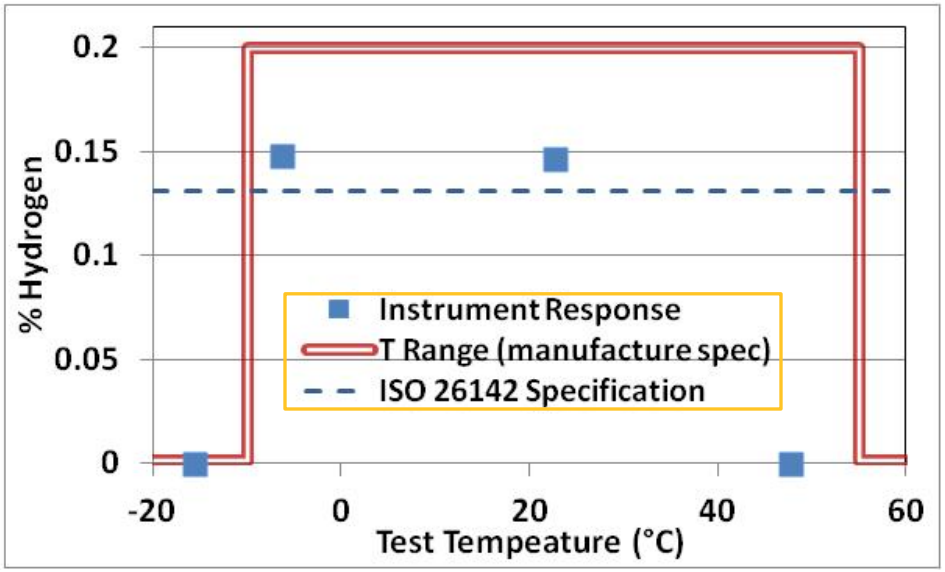
Manufacturer Feedback

Sensor tested at NREL's Sensor Testing Laboratory

H2 exposures at various temperatures (T)



Net response to 0.19% H2 challenge at various T



- Technology subjected to NREL-developed test protocol
- Results reviewed with manufacturer
- Identified "out of performance specification" (internal heater caused premature fault)
- NREL-suggested remedy was acknowledged and implemented

Note: Names removed for confidentiality

William J. Buttner, Ph.D.
Senior Scientist I
MS 1613
Hydrogen Technologies & Systems Center
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401

Dear Mr. Buttner:

I would like to thank you and Matthew Post for the testing that you performed on our hydrogen gas detectors. It is always good to have an independent organization with "fresh eyes" evaluate technologies. We are very pleased with the quality of your tests, the performance of our products and the insights that the testing provided

Based on the insights gained from your testing we are actually going to implement some product enhancements to further advance the performance of our products.

Again, thank you and you team for their efforts and please let them know that their efforts are appreciated and the data that they generated will be used to further enhance our products.

Industry Applications Support

Purpose: ***To provide the fuel cell industry with hydrogen sensor consultation and guidance***

Each specific hydrogen sensor application requires a unique set of performance capabilities. Selection of the proper type of sensor to meet these requirements will dictate whether the application succeeds. NREL is working with end users in automotive, stationary, industrial truck, and power applications to support improved applications methods.

Fuel Cell Activities

William Buttner
National Renewable Energy Labs
30Sep11

Hello Bill-

I wanted to take a moment to thank you for the open, candid, and productive discussions that we've had over the past 10 months pertaining to hydrogen sensors for use in [redacted] fuel cell vehicles. When we first began our discussions, our group needed to quickly learn about hydrogen sensors for our particular automotive usage. As you know, our facility has extensive knowledge in hydrogen fuel cells, however, we recently identified a new need for a dedicated hydrogen sensor for use in the hydrogen loop of the system. (We are quite familiar with hydrogen sensors for in-lab use and for leak detection, however, our previous generation systems had not operated with an in-process, dedicated sensor designed for high volume production.)

[redacted] I spent several months scouring the technical landscape for possible technology types as well as available products from suppliers. The numerous conversations that we had with you and your team as well as the on-site visit by your team in January were very informative and helpful as we worked to quickly gather information and come up to speed on the options available to us. Clearly your technical knowledge in the area of hydrogen sensors is vast, and I believe the discussions benefited both our effort to identify a quick and viable solution and highlighted to your commitment to making hydrogen fuel cell vehicles a viable transportation option in the near future.

Please send my regards along to your team for their knowledge, professionalism, and counsel pertaining to our hydrogen sensor search.

Kind regards,

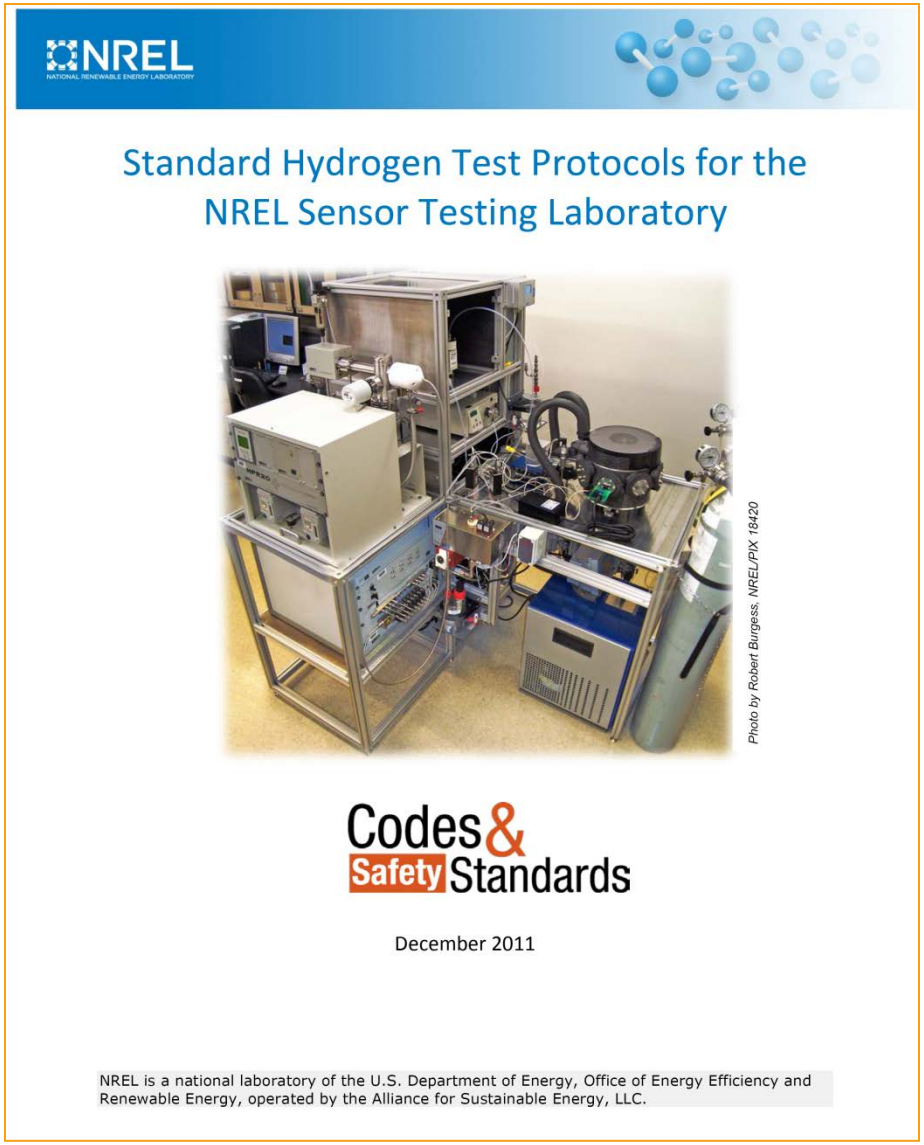
Note: Names removed for confidentiality

Letter of recommendation example

Developing Standards for Sensor Characterization

Purpose: ***To develop sensor test protocols that accurately characterize critical user performance parameters***

- Working group participation on national and international sensor test standards (ISO, UL, FM)
- Published NREL peer review test protocol summary document
- Collaboration on hydrogen sensor textbook (BAM, JRC)



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Standard Hydrogen Test Protocols for the NREL Sensor Testing Laboratory

Photo by Robert Burgess, NREL/PIX 18420

Codes & Safety Standards

December 2011

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

http://www.nrel.gov/hydrogen/pdfs/53079.pdf

Hydrogen Sensor Workshop and Task Group

Hydrogen Sensor Workshop (June 8, 2011)

- Identify critical applications
- Identify shortcomings or deficiencies
- Assign performance specifications and estimate gaps
- Existing and emerging markets
- Attended by cross section of stakeholders
- Results and findings presented in NREL report (currently under review)

NREL Hydrogen Sensor Task Group (on-going)

- Continuation of the Workshop
- Open to all stakeholders in the H2 community
  - CDOs and SDOs
  - End users
  - Developers
- Current focus on N. America needs (may expand)
- SharePoint site open to all participants (database, minutes and other documents, open blog, etc.)
- Quarterly Web meetings (topical talks, discussion)

Hydrogen Sensor Workshop

The Department of Energy (DOE) through the National Renewable Energy Laboratory (NREL) invites you to participate in a one-day workshop on hydrogen sensors, with emphasis on safety as well as process control requirements. The workshop shall identify and review sensor applications and required performance specifications for each application. Attendees shall represent a cross section of the hydrogen industry. Participants must preregister for the workshop.

To encourage interaction and open discussion, we are limiting the attendance to this workshop to 50 active participants. A diverse group is expected to attend this workshop providing sensor end-users and sensor developers the opportunity to work together to identify existing and emerging markets and to identify areas for improvements in sensor technologies. Participants will consist of stakeholders in product development, infrastructure support, health and safety, as well as sensor developers.

We hope you will be able to join us for this free workshop to learn more about the emerging use of hydrogen sensors. The discussion and outcomes of this workshop are vital to the hydrogen community and our nation as we shift to a greater use of hydrogen technologies.

DATE & TIME:
Wednesday, June 8, 2011
8:00AM – 5:00PM

LOCATION:
Donald E. Stephens Convention Center
Rosemont, IL

MORE INFORMATION:
Please contact Jessica Cole at MorEvents **888-329-0664** or **jessica@morevents.com**

Held in conjunction with
sensors expo & conference
JUNE 6 - 8, 2011 • ROSEMONT, IL
DONALD E. STEPHENS CONVENTION CENTER

Organized by:
NREL NATIONAL RENEWABLE ENERGY LABORATORY
U.S. DEPARTMENT OF ENERGY

The H2 Sensor Task Group will have a side meeting during the AMR

Developmental Sensor Partnerships

NREL works closely with organizations that are developing near-term hydrogen sensor technologies

- LANL/LLNL – Multiple rounds of testing completed on prototype sensor. Results led to prototype modifications with added thermal feedback control and electronics upgrade
- IOS – Multiple rounds of testing completed on prototype sensor with custom designed tests designed for improved electronics package algorithm upgrade
- ORNL – Discussion of sensor technology and packaging requirements for ORNL technology to be redesigned into a deployment-ready configuration that can be incorporated into NREL's hydrogen sensor testing apparatus
- Element One, MOA (Memorandum of Agreement) is in place to provide NREL shared lab space and to work on deployment and demonstration activities using NREL's wind-to-hydrogen site

International Collaboration (MOA with JRC-IET)

NREL-JRC/IET Collaboration

- **MOA implemented October 2010**
  - Common program objectives are met through leveraged accomplishments in hydrogen safety sensor research and development
  - First annual steering committee meeting held September 2011
  - Recognized at IEA Task 31 meeting as an exemplary model for international collaboration
- **Sensor Interlaboratory Comparison (SINTERCOM)**
  - Acquired final sensor for SINTERCOM (MEMs MOX)
  - Life tests ongoing (Pd, MOS, TCD [2], EC)
  - Interferent testing of sensors
- **Topical studies**
  - Oxygen dependence
  - Assess improvements/degradations MEMs sensor
    - Team expanded to include Univ. of Quebec
  - Hydrogen detection via oxygen displacement
- **Outreach (publications and expansion)**
  - Joint IJHE paper (oxygen dependence)
  - Collaborative presentations at conferences (ICHS, FCHEA)
  - ICHS Co-Chairs for mitigation session
  - SINTERCOM Report (JRC technical report)
    - Full NREL report on SINTERCOM in process
  - WHEC Abstract (MEMS sensor technology)
    - University of Quebec

JRC Technical Notes

Interim Report of the SINTERCOM Project

Black, G.[1], Boon-Brett, L.[1], Harskamp, F.[1], Moretto, P.[1]
Buttner, W. J.[2], Post, M. B.[2], Burgess, R.[2], Rivkin, C.[2]

[1] European Commission, DG Joint Research Centre, Institute for Energy – Cleaner Energy Unit, P.O. Box 2, 1755 ZG Petten, The Netherlands.
[2] Hydrogen Technologies & Systems Center, National Renewable Energy Laboratory, Golden CO 80401, USA.

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Clean Energies

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Golden, CO 80401-3393

EUR 24854 EN - 2011

JRC EUROPEAN COMMISSION

Future Direction of Sensor Development Testing

- **Impact on sensor performance following exposure to 100% hydrogen**
  - Develop test protocol to assess impact on the sensor following short-term (<1 h) exposure to pure hydrogen or high concentrations
  - Short-term implementation (possibly within the year)
  - Small total volume of hydrogen (<0.5 L)
  - Test apparatus, test plan will be reviewed with EHS office prior to implementation
- **Expanded interferent studies**
  - Potential number of possible interferents is large
  - New priority interferent may be identified
  - Short-term implementation (possibly within the year)
  - Test apparatus, test plan will be reviewed with EHS office prior to implementation
- **Process control sensors**
  - Develop apparatus and test protocol to investigate sensors designed to (continuously) operate in pure or high hydrogen concentrations
  - New fixture, ESIF
  - Long-term implementation (beyond current year)
  - Test apparatus, test plan will be reviewed with EHS office prior to implementation, which will include SOP and RV

Component Standard R&D

Component R&D Relevance/Approach

Relevance: Hydrogen component safety standards are needed for the rapid deployment of a reliable and safe hydrogen infrastructure

SAE J2579 Validation Testing

Approach: NREL is closing technology gaps by conducting hydrogen component R&D, both through NREL internal testing efforts and through subcontract programs

Component R&D Accomplishments

- **Codes and standards technical committee accomplishment summary**
  - NREL has put in place two subcontracts to provide reporting summarizing current codes and standards R&D needs
  - NREL has supported RCS activities for automotive, stationary, industrial truck, and transit applications includes support of SAE, CSA, NFPA, ASME, UL, ISO and GTR activities
- **Completed final report "HPRD1 Hydrogen Service Suitability Test Validation Program" September 2011**
  - Results used by HPRD1 technical committee to modify test sequences based on validation test results that identified extreme conditions beyond realistic service limits

Component R&D International Activities

- **ICHS summary presentation of component test results**
  "Validation Testing in Support of Hydrogen Codes and Standards Development" at the September 2011 ICHS conference in San Francisco, CA
  - This paper presented test results from four separate NREL validation test programs to international stakeholders
  - This paper has been published in the 2011 ICHS proceedings and approved for IJHE special issue
- **Presented at HYSafe Hydrogen Safety Workshop, September 2011, on hydrogen on board storage standards and SAE perspective to the international community**
- **Supported development of Hydrogen Fueled Vehicle GTR (Global Technical Regulation) for safety and durability of on board hydrogen and electrical systems through subcontracts with technical experts**
  - Findings presented in technical reports distributed to DOE and International Stakeholders

Component R&D Proposed Future Work

- Create prioritized list of component standards validation testing needs
- Establish mechanism to validate composite tank standards and test requirements for tank level stress rupture (participation in upcoming NASA WSTF composites conference August 2012)
- Continue to work directly on codes and standards technical committees to provide technical support and validation testing as these technical documents progress to the level of full standard
- Develop user facility capabilities in new NREL ESIF building

ESIF - Energy Systems Integration Facility
Completion of new NREL facility scheduled for early FY13, to include sensor lab, components lab, and high pressure test lab

Summary

DOE Summary Slide of Sensor Lab Accomplishments

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Overview of the NREL Hydrogen Safety Sensor Testing Laboratory

U.S. DEPARTMENT OF ENERGY

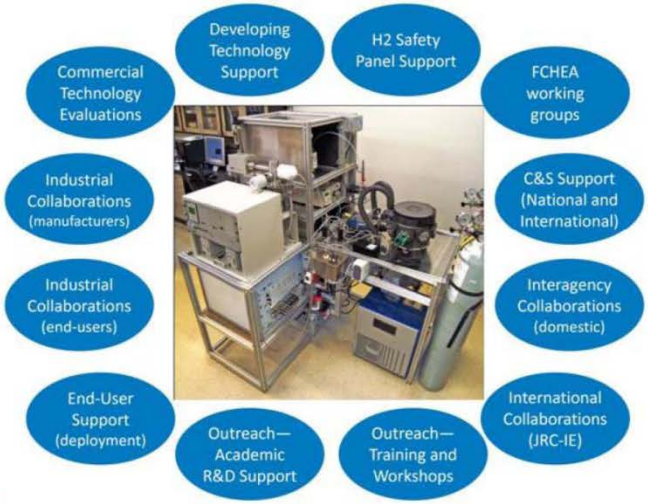
The NREL sensor laboratory strives to ensure that sensors are available to meet user needs

Mission and Activities

"Around-the-clock" sensor performance testing
- Fully automated sensor test apparatus
  - Controlled and monitored T, P, and RH
  - Gas parameter control (flow and composition)
- Independent assessment to DOE targets, gas standards (e.g., ISO, UL) or user requirements
- Quantitative sensor performance assessment

Partnerships with the hydrogen community
- Manufacturers – to improve performance
- End user support – expert advice and testing
- Support code and standard development
- National and international collaborations and markets
- Available as a facility for contract work

Outreach – Support of Stakeholder Activities
- Workshops, working groups, and site visits
  - 2011 DOE-NREL Sensor Workshop
  - Hydrogen Sensor Task Group and WEB Meetings
- Hydrogen panels: IEA, FCHEA, Codes & Standards



Contact

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Carl Rivkin (303) 275-3839, carl.rivkin@nrel.gov

NREL Hydrogen Safety Sensor Testing Laboratory
William Buttner (303) 275-3903, william.buttner@nrel.gov
Robert Burgess (303) 275-3823, robert.burgess@nrel.gov

http://www.nrel.gov/hydrogen/facilities_hsl.html

Summary

Relevance: Safe deployment of hydrogen fuel cell technologies is dependent on components that are proven to meet new safety and performance standards

Approach: NREL is closing technology gaps by conducting hydrogen component R&D, both through NREL internal testing efforts and through subcontract programs

Accomplishments & Progress: NREL's component R&D accomplishments have provided a sound technical basis for new hydrogen codes and standards requirements and have supported industry by providing independent third party assessment of performance against those requirements

Collaborations: Collaboration with codes and standards technical committees, component manufacturing industrial partners, and hydrogen fuel cell applications experts has been a key part of NREL's success in advancing component program objectives

Proposed Future Work: NREL will continue to work with codes and standards technical committees to move documents toward release as full standards by closing R&D gaps and providing component manufacturers support in developing products that meet these safety and performance standards