NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

2009 DOE Annual Merit Review
Hydrogen Program & Vehicle Technologies

Hydrogen Safety Sensors

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Hydrogen Technologies & Systems Center

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Overview

TIMELINE

- *Start date*: **April, 2007**
- Hydrogen safety sensor targets defined at workshop held in D.C.
- *End date*: **September, 2012**
- Multi year DOE RD&D target date
- *Percent complete*: **25%**

BUDGET

- Funding in FY08:
  - **$300K** (+$250K capital)
- Funding for FY09:
  - **$600K** (+250K capital)

BARRIERS

- ***Consensus*** - Achieving national agenda on codes & standards *(A,B,D,L,J)*
- ***Representation*** – Government & Industry support and DOE role *(F,G,H,I,K)*
- ***Technology Readiness*** – Jurisdictional issues, available codes and sensor certification *(M,N)*

PARTNERS

- UL *(Underwriters Laboratory)*
- IIT *(Illinois Institute of Technology)*
- JRC *(Joint Research Center)*, Institute for Energy, NL
- Federal Institute for Material Research and Testing, DE
- ISO TC 197 WG13
- Sensor & Detector Manufacturers

Relevance— *Objectives*

Phase I

– independent evaluation of hydrogen safety sensor performance from 0 to 4% hydrogen
– support hydrogen sensor codes and standards development
– test and validate new sensor R&D
– work closely with manufacturers to improve sensor performance to meet DOE 2012 targets

Phase II

– collaboration between industry and government agencies for sensor testing validation
– establish premier sensor test laboratory for calibration and pre-certification of hydrogen safety sensors
  - capability to test to 100% hydrogen concentration in air
  - modeled after NREL NCPV (National Center for Photovoltaics) device/module testing

Relevance— *Background*

Why Sensor Testing is Needed

- Safety requirements specify the use of gas detection
  - NFPA 2 “Hydrogen Technologies Code", section 10.2.14 Dispensing equipment shall be provided with gas detectors, leak detection, and flame detectors such that fire and gas can be detected at any point on the equipment.
- DOE sponsored workshop held April 2007 defined safety sensor targets


MPA Home

MPA-11 sensors & electrochemical devices

Applying fundamental knowledge of materials science and electrochemistry to National Security challenges

Hydrogen Sensor Workshop REPORT

Wednesday April 4th, 2007

Doubletree Hotel Washington DC

Hosted by LANL and Co-hosted by LLNL

for the DOE Hydrogen, Fuel Cells & Infrastructure Technologies Program

Purpose: to draft technical requirements and targets for hydrogen safety sensors

- Benchmarks can be achieved with DOE/NREL support

Approach

- Characterize sensor market and identify gaps relative to DOE performance targets
- Improve sensor performance by working closely with sensor manufacturers, providing technical and laboratory testing support
- Support commercialization through development of codes and standards for sensor certification

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)

Source: DOE Multi year RD&D Plan

Technical Accomplishments and Progress

Market Definition

- Determine safety sensor market needs through interaction with key stakeholders

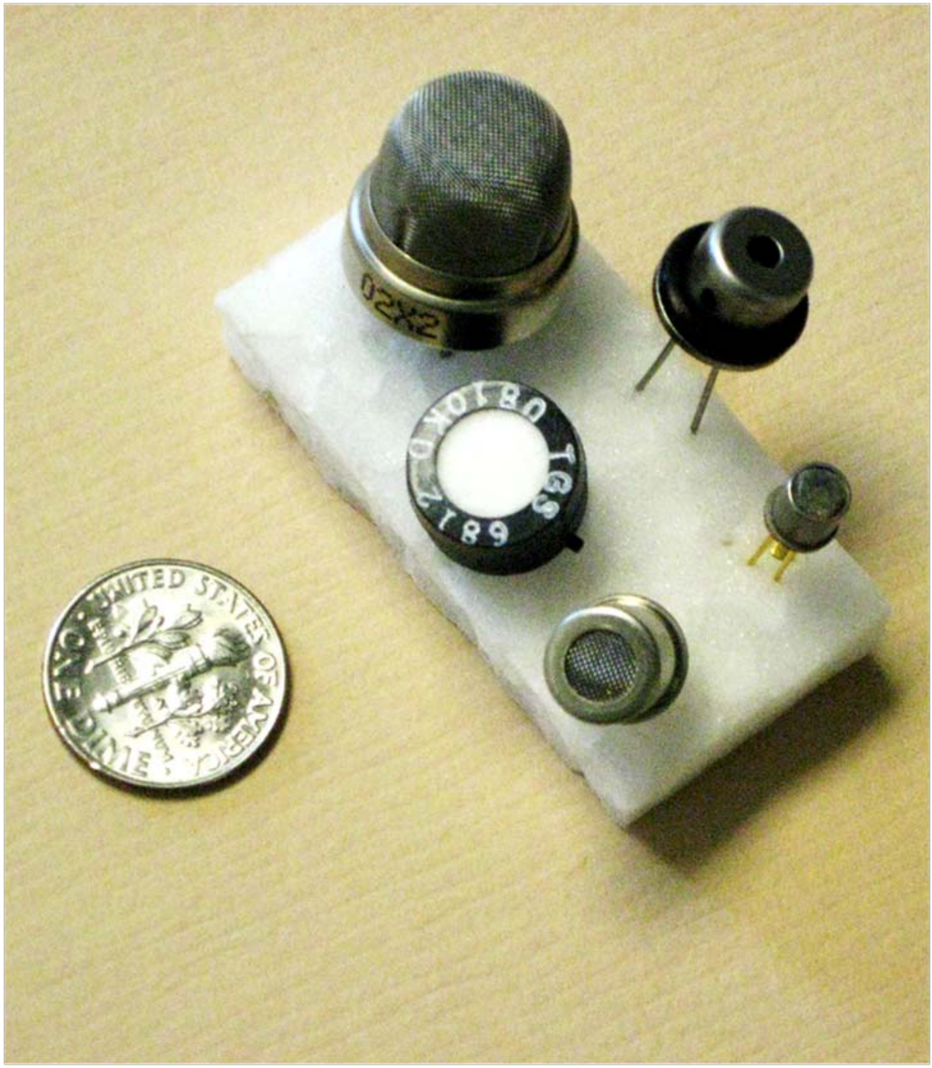
Manufacturers	*Systems design companies*	*Testing and certification labs*	*CDO's and SDO's*	*End users*

- Created compilation of safety sensor technologies
  - Over 120 sensor and detector products identified so far

Technical Accomplishments and Progress

Market Definition

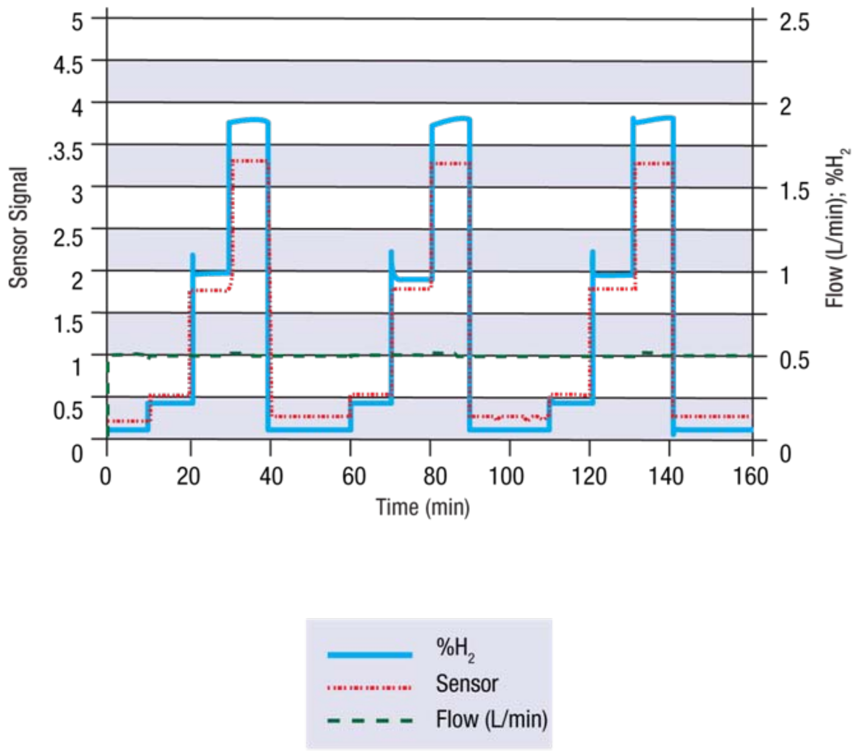
- Electrochemical
- Amperometric, potentiometric [low T and high T]; solid/liquid electrolyte
- Pd-film and Pd-alloy films
- Electronic -Resistor, capacitor, transistor,
- Thermoelectric
- Optical evanescent wave
- Mechanical [SAW, cantilever]
- Metal Oxide (MOX sensors)
- Heated metal oxides
- “Pellistor”-type combustible gas
- Hot Pt or Pd catalyst with Pt resistance thermometer
- Thermal conductivity – non selective; semi-selective
- Optical Devices
- Colorimetric and indicator dyes
- Evanescent wave – with film of Pd or other material



Technical Accomplishments and Progress

Response Test & Short Term Stability

- Response test is repeated using automated test process
- Multiple runs and statistical analysis to quantify sensor performance parameters

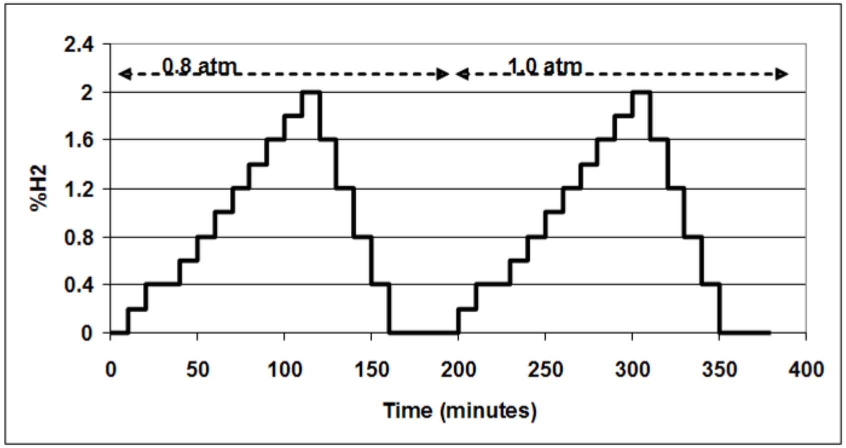


Technical Accomplishments and Progress

Linearity

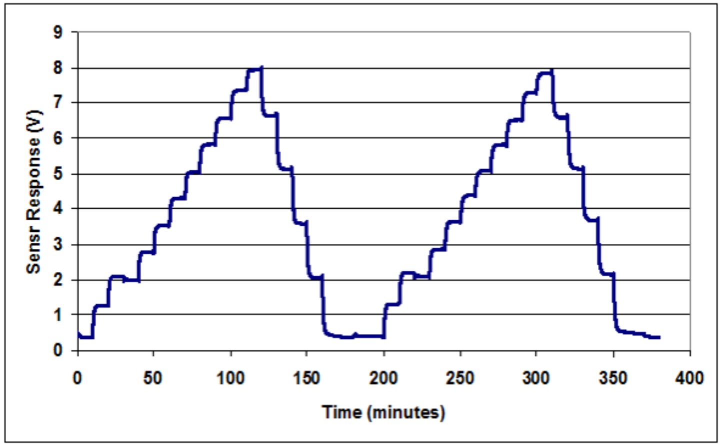
Input parameter

- Repeatable, automated input
- Computer controlled volumetric % hydrogen in air



Output response

- Measured response/recovery
- Determination of numerous sensor parameters

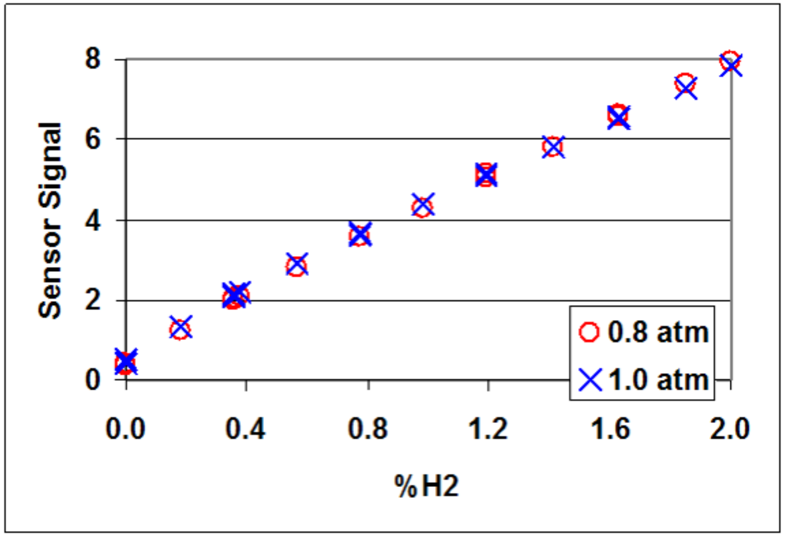


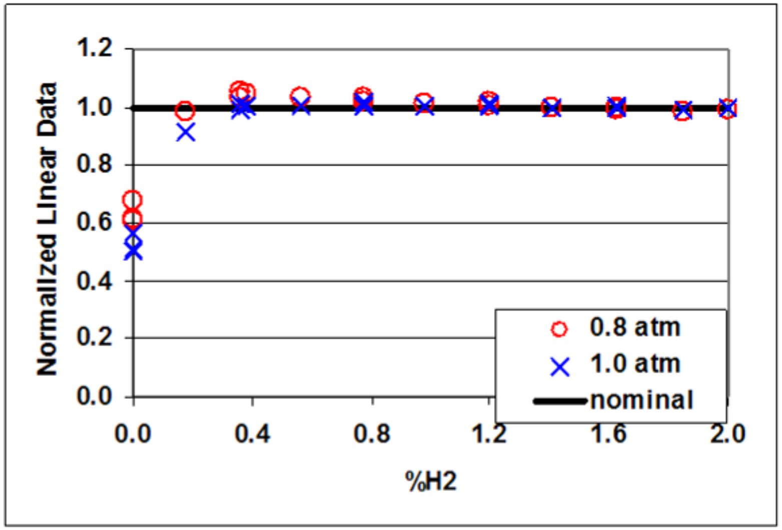
Technical Accomplishments and Progress

Analysis of Linearity Test Data

- Quantitative determination of sensor dynamic range (to 50% LFL)
- Linearity test is used for lower detection limit determination
- Normalized linear plot vs. % hydrogen concentration in air depicts linear range

Lower detection limit is a critical parameter for sensor applications



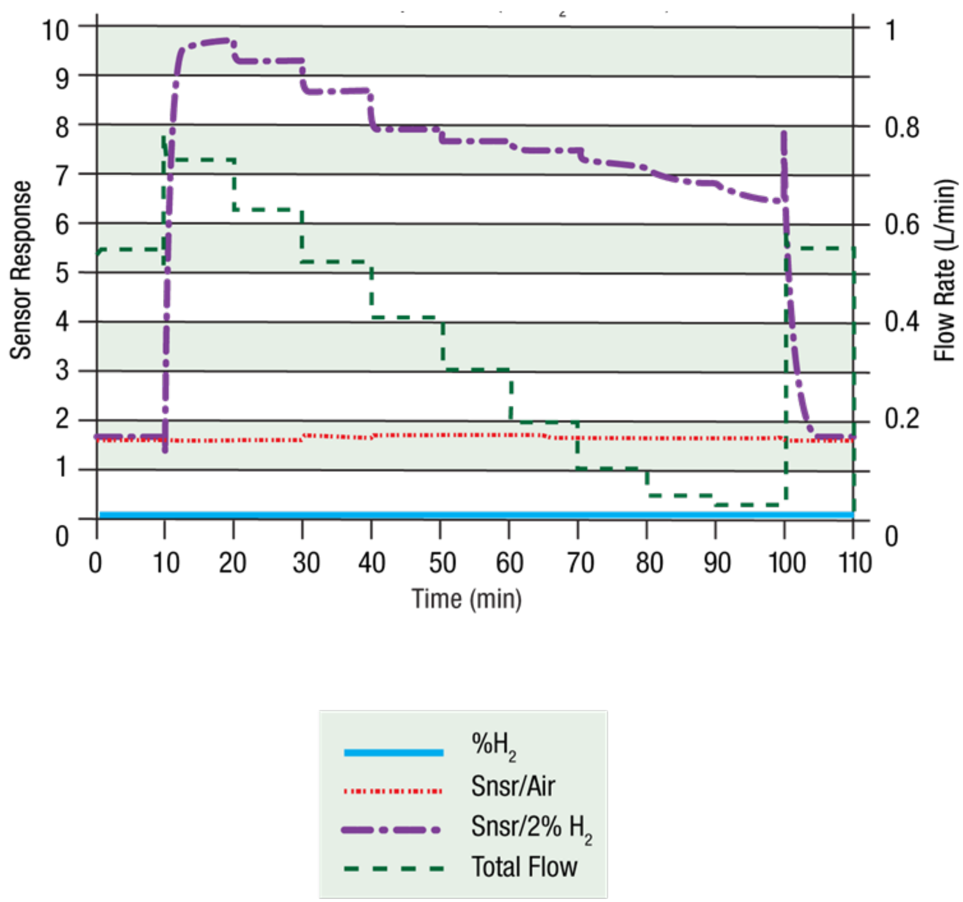


Technical Accomplishments and Progress

Environmental Effects

- Standard test protocols designed to examine environmental effects on sensor output
- Relevant test capabilities include variation of input parameters, including; *temperature, pressure, humidity, orientation, gas flow and interferants*

Example: Gas Flow Effects



Technical Accomplishments and Progress

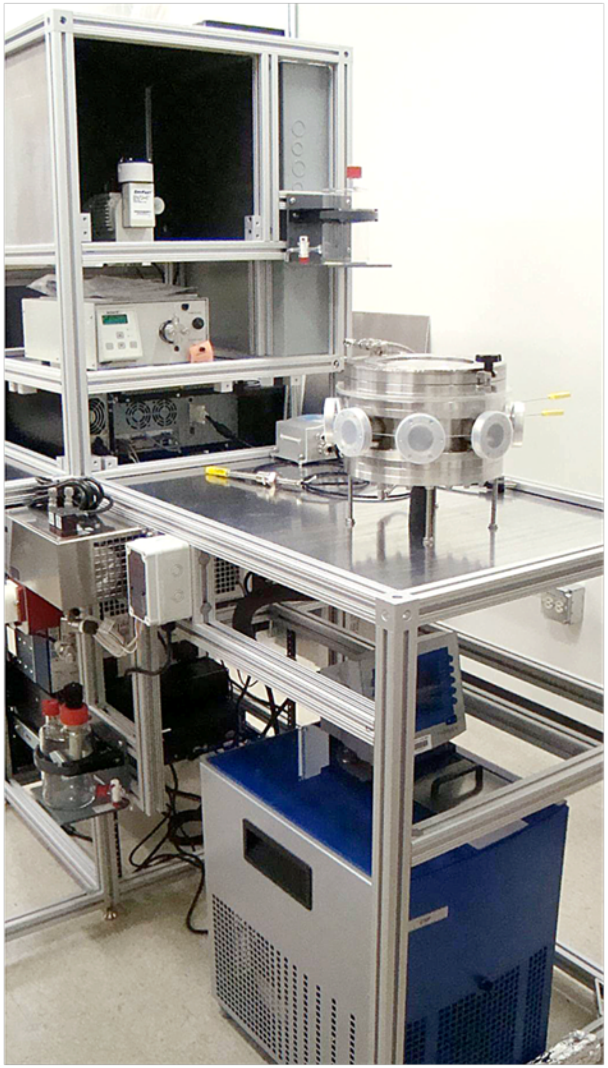
NREL Test Chamber Design

- Concurrent testing of multiple sensor
- Easy access with side port feed through and top chamber viewing port
- Custom welded housings with integral fluid passages for temperature control

Technical Accomplishments and Progress

NREL Test Apparatus

- Partial assembly as of March 2009
- Environmental system controls for temperature, pressure and relative humidity
- Automated control and data acquisition



Technical Accomplishments and Progress

Published Sensor Lab Fact Sheet

Hydrogen Technologies

Hydrogen Sensor Testing

NREL researchers William Buttner and Matthew Post setting up a test for a commercially available hydrogen sensor. Because hydrogen is colorless and odorless, sensors are key safety elements of fueling stations and other hydrogen facilities. Pix 15977.

Highlights

Because hydrogen is colorless and odorless, sensors will be key safety equipment for safe fueling stations and other hydrogen facilities. Sensors can be used to detect releases, automatically shut down systems, activate alarms, and notify emergency responders.

A number of companies are making sensors, but they are using several different technologies, experience is limited, and they need to meet certification standards.

NREL researchers are using a new hydrogen sensor laboratory to test the various sensors available against DOE performance targets and work with manufacturers to meet performance targets.

Hydrogen is no more dangerous than current transportation fuels, but it is different. One key difference is that hydrogen is colorless and odorless and its flames are virtually invisible in daylight. Hydrogen detectors will therefore be a key part of safe design for hydrogen fueling stations and other hydrogen facilities. How do we ensure that those detectors are reliable and do everything they need to do?

Many pieces will need to be put in place for hydrogen fuel cell vehicles to become a major part of our transportation structure. Among those pieces, dependable detectors are needed to keep concern about safety from being a missing nail in the horseshoe. A number of companies are producing hydrogen sensors, but they rely on several different technologies, most are relatively new products, and they need to meet emerging certification standards. National Renewable Energy Laboratory (NREL) scientists are using a new hydrogen sensor laboratory to test the various sensors available, check their performance against U.S. Department of Energy (DOE) targets for sensor performance, and work with manufacturers to meet performance targets.

Hydrogen has been used extensively for many years in industrial applications, with an excellent safety record. With growing fuel cell uses such as powering forklifts and providing back-up power for cell-phone towers—and particularly the anticipated emergence of fuel cell vehicles—hydrogen is increasingly being used in locations that are publicly accessible. This requires more foolproof safety measures than are typically used in more controlled industrial applications. Sensors are a key part of such enhanced safety systems. They can detect releases of hydrogen and shut down systems automatically, activate alarms, or send information to emergency responders. Thus, effective and dependable sensors will play a vital role in safe general public use of hydrogen and NREL testing can help ensure their availability.

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Performance Measures

Each sensor technology has particular strengths and weaknesses and each needs to be tested against various concerns and requirements, both generally, and for the various specific applications and settings in which they might be used. Some general concerns with sensor performance include:

- Whether they will give false positive readings
- How they will react to exposure to moisture
- How they will react to exposure to temperature extremes
- How reliable they will be over time
- What maintenance they will require.

In addition, the DOE has set several specific performance targets for sensors:

- Measurement range coverage of 0.1%–10.0% concentration
- Operation in temperatures of -30°C to 80°C
- Response time less than 1 second
- Accuracy within 5% of full scale
- Function in an ambient air gas environment within a 10%–98% relative humidity range
- Lifetime greater than 10 years
- Resistance to hydrocarbon and other interference.

Current Sensors and Planned Test Lab Capability

Sensors can be generally categorized into six basic types: electrochemical, palladium and palladium alloy film, metal oxide, pellistor, thermal conductivity, and optical/acoustic devices.

Staff in the NREL Hydrogen Sensor Test Laboratory will be able to test a wide range of viable sensor types. Researchers will examine any new sensor technologies to evaluate whether these should also be tested. All sensors will be tested using the manufacturers' performance specifications and with procedures consistent with recognized national and international test methods. In addition, researchers will use the lab to monitor long-term sensor performance to help define maintenance requirements. The data generated are intended to help sensor manufacturers improve the performance of their products and reduce testing expenses. Data will remain confidential in a manner to ensure that all business information is protected.

NREL is collaborating in this work with the JRC (Joint Research Centre) Institute for Energy, located in Petten, the Netherlands, which is doing similar work in Europe and the Illinois Institute of Technology (IIT), which has also done considerable work in the area. NREL also works closely with hydrogen safety codes and standards development organizations including Underwriters Laboratories and others, to see that hydrogen sensors can meet certification performance requirements.

Progress to Date

As of October, 2008, the laboratory is up and running and a scientist and sensor expert from IIT has now joined the NREL staff. More than a dozen sensors—covering the six current technologies—have been acquired with additional acquisitions planned. Testing has started and a quality assurance process is being performed to verify the testing procedures. Already, the first test results are being shared with the sensors' manufacturers. Permanent equipment for an advanced NREL test facility has been ordered and should be largely in operation by October 2009. The primary pieces of equipment are specially designed test chambers to accommodate the multiple sensor types, environmental control systems, gas analysis equipment, and data acquisition and control devices for consistent, repeatable test conditions.

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Hydrogen Technologies

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http://www.nrel.gov/hydrogen/pdfs/42987.pdf

Collaborations

Sensor Manufacturers

- Over 120 manufacturers identified so far, contacts with 20%
- CRADA (cooperative research and development agreement) for hydrogen sensitive paint development and RFID sensor
- Licensing NREL intellectual property for sensor commercialization

Industry/Government/University Collaboration

- IIT (Illinois Institute of Technology) sensor lab
- IEEE hydrogen release from batteries
- NASA hydrogen safety

Codes & Standards development organizations

- UL 2075 "Gas and Vapor Detectors and Sensors", member of standards working group
- ISO TC 197 "Hydrogen Technologies", member of working group 13, hydrogen safety sensors, drafted standard ISO DIS 26142, hydrogen specific standard for sensor testing

Collaborations

International Collaboration

- JRC (Joint Research Center), Institute for Energy
  - European commission laboratory located in Petten, Netherlands
  - Similar hydrogen safety sensor testing program
  - Collaborating on testing protocols & sensor technologies
- Federal Institute for Material Research and Testing
  - Government laboratory in Berlin, Germany, also known as BAM (Bundesanstalt für Materialforschung)
  - Standards and testing laboratory

JRC Sensor Test Apparatus

http://ie.jrc.ec.europa.eu/

Proposed Future Work

- Perform wider range of environmental tests utilizing new NREL test apparatus
- Expand efforts with sensor manufacturers to expedite progress toward meeting DOE sensor performance targets
- Design/build phase II apparatus for testing wider range of hydrogen concentrations
- Continue collaboration with key stakeholders, establishing benchmarks and test method protocols
- Work toward improved codes and standards for safety sensor certification
- Integrate CFD leak scenario analysis with sensor program to validate sensor placement

Summary

Work directly with hydrogen safety sensor manufacturers, supporting research and development efforts through technical support and standardized testing. *Particular focus on enabling technologies*

Support hydrogen sensor codes & standards development by direct support of standards development organizations

These goals can only be accomplished through collaborations with key stakeholders at all levels