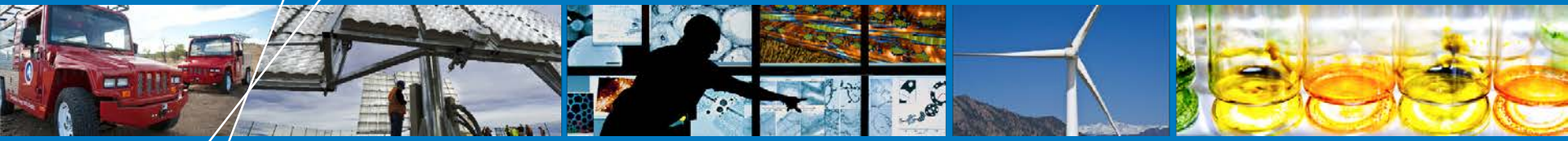
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

NREL Hydrogen Sensor Testing Laboratory



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June 9, 2015

***Intern--Colorado School of Mines, Golden, CO**
#Graduated and entered the real world

Project ID **#SCS021**

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

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

- **Project start date:** 10/01/2010
- **Project end date:** 09/30/2015*

  * Project continuation and direction determined annually by DOE

Budget

- **FY14 DOE funding**: $ 335K
- **FY15 planned DOE funding**: $350K
- **Total DOE funds received to date**: $2220K

Barriers

C. Safety is Not Always Treated as a Continuous Process

F. Enabling national and international markets requires consistent RCS

G. Insufficient technical data to revise standards

Partners

- **Industry:** component manufacturers, automotive OEMs, KPA Inc., Parker Aerospace, Element 1, ASC LLC
- **Government labs and agencies:** JRC, BAM, DOT-NHTSA, CaFCP, LANL, LLNL, IEA-HIA. NREL (cross-cutting programs)
- **Academic:** CO School of Mines
- **Support of standards:** UL, CSA, FM Global ISO, NFPA, GTR/FMVSS, SAE, ASTM

Relevance: Role of Sensors for Safe H_2 Deployment

- **Provide critical safety factor**
  - Alarm at unsafe conditions
  - Ventilation activation
  - Automatic shutdown
- **Bad things can happen when sensors are not used (properly)** [www.h2tools.org/lessons]
  - "Gaseous Hydrogen Leak and Explosion"
    - Lack of H_2 detection: "Hydrogen Explosion and Iron Dust Flash Fires in Powdered Metals Plant"
    - No combustible gas monitoring or training
  - "Two False Hydrogen Alarms in Research Laboratory"
    - Nonspecific sensors alarmed twice ($10,000 fine)
    - H_2 specific sensors are now installed
- **Mandated by code**
  - NFPA 2 (Sections 10.3.19.1 and 3.3.219.2.2)
  - IFC (Repair garages, other indoor operations)
  - NFPA 2 is referenced in IFC

Hydrogen dispenser equipped with wall-mount and internal sensors

Relevance: Why Test and Evaluate Sensors

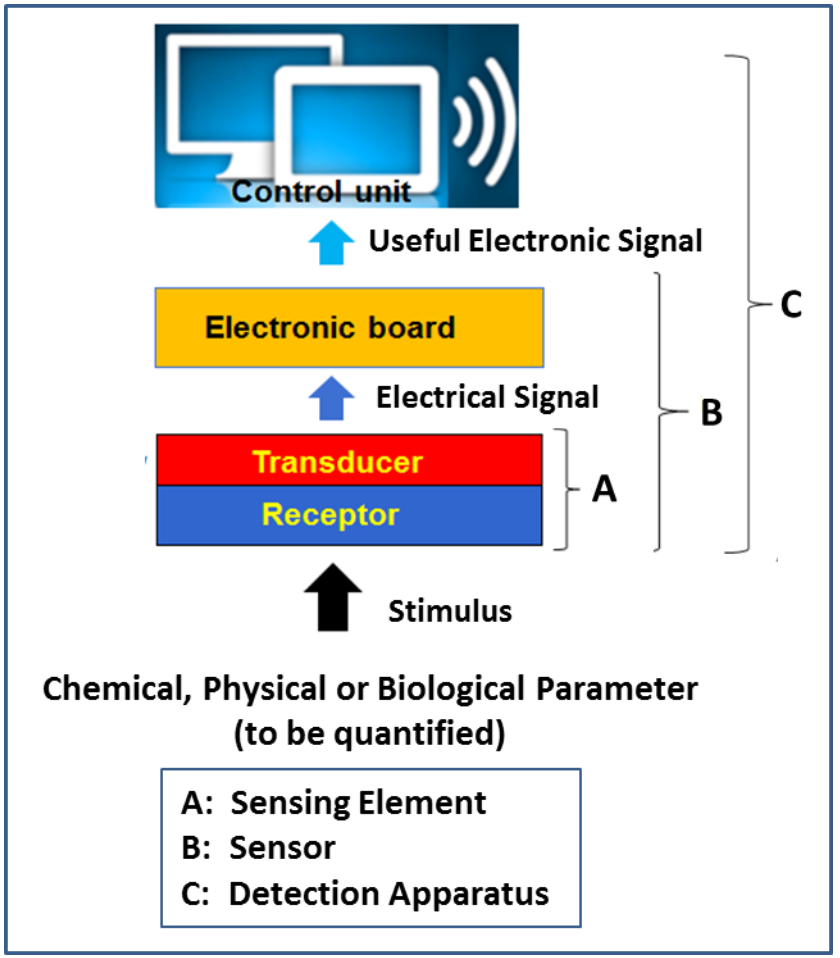
"H2 Sensors Don't Work"
- Not true
- Not totally untrue
  - 1/3 of sensors tested out of spec. (2013)
  - Unacceptable failure rate in the field
  - Wrong sensor for application

Emerging Markets
- New applications (end-users)
- New sensor technology (manufacturers)

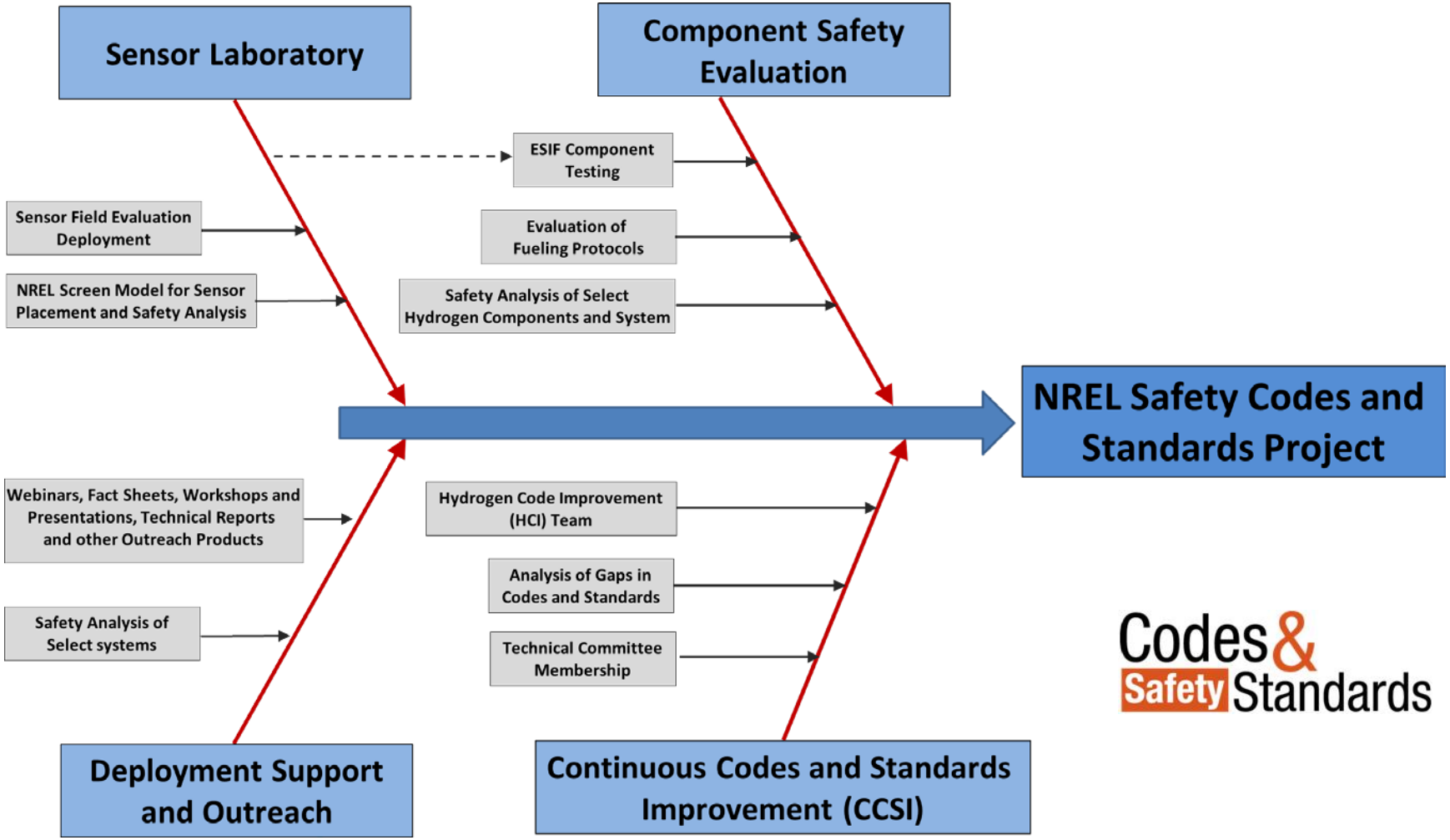
Expectations of Performance
- Sensors can be used improperly
  - Matrix Effects
  - O_2 Displacement
- Fundamental Gaps
  - How to properly qualify sensors
  - Guidance on placement/location
  - Cost of ownership

Support of Codes & Standards
- ISO 197
- GTR Hydrogen Vehicles
- SAE (TIR, in development)
- UL 2075 STP

WHAT IS A SENSOR?



Approach: NREL SCS Project Structure



Codes & Safety Standards

The NREL Sensor Testing Laboratory is an integral part of the NREL Safety Codes and Standards Group

Approach: Functions of Sensor Testing Laboratory

- **Assessment of H_2 sensing element, sensor, detection apparatus performance**
- **Interact with manufacturers to improve sensor performance to meet targets, e.g., ISO 26142, DOE, specialized applications**
- **Support hydrogen sensor codes and standards development (national and international)**
- **Support end-users (deployment)**
  - "Topical Studies"—information on sensor use
  - **Direct collaborations** with the H_2 Community
- **NREL Sensor laboratory does not certify**
- **Client confidentiality**

The NREL Sensor Testing Facility

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

Collaborations: Strategic Partnerships

Industrial Partnerships

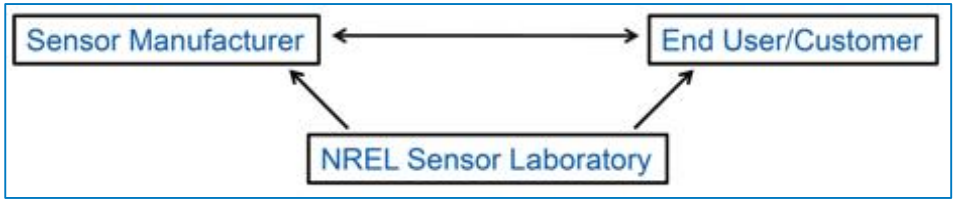
- Six formalized agreements
  - Primary: Direct support of deployment
    - Vehicle OEM and Stationary
  - Secondary: technology development

Government Agencies (National/International)

- NREL-JRE/IET (MOA, DOE-EU Common Call)
- National Laboratories

"Ad Hoc" Support/Collaboration

- US DOT-NHTSA (support of the FMVSS)
- Federal Institute for Materials Research and Testing (BAM) Berlin
- Water Electrolysis Safety (H_2 limits in O_2 stream)
  - NASA (Breathing Air)

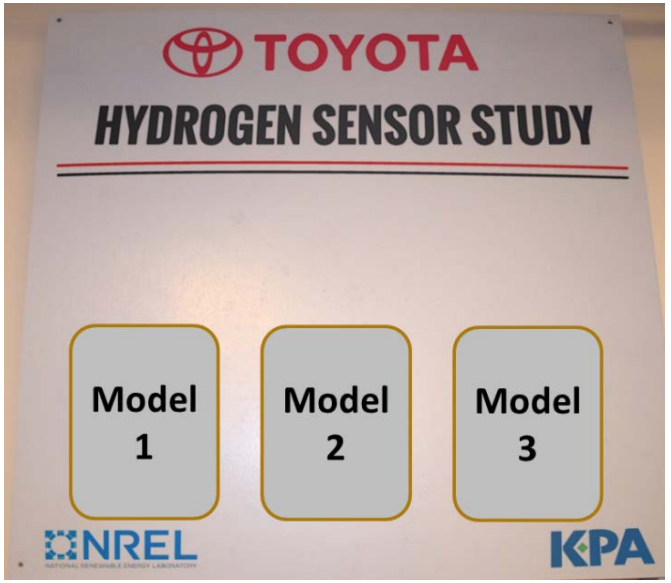


Much of the sensor laboratory activity is in direct support of end-users and deployment

Accomplishments and Progress

Support of Deployment/Infrastructure (Industrial Partnerships)

- **Application: Hydrogen vehicle repair facility (sensors mandated by IFC)**
  - Workplan: Define sensor requirements; identify/acquire potential sensors; laboratory assessment and multi-phase field deployments , and evaluate
  - Technical Challenge: compatibility of sensors to function in identified application
- **Project Overview**
  - CRADA implemented March 2014
  - Sensor selection with guidance from NREL
  - Simultaneous field and laboratory deployment
  - Supplemental laboratory evaluations
  - Evaluation phase end date: December 2014
- **Outcome/Significance**
  - Qualify hydrogen Safety Sensor for repair facilities



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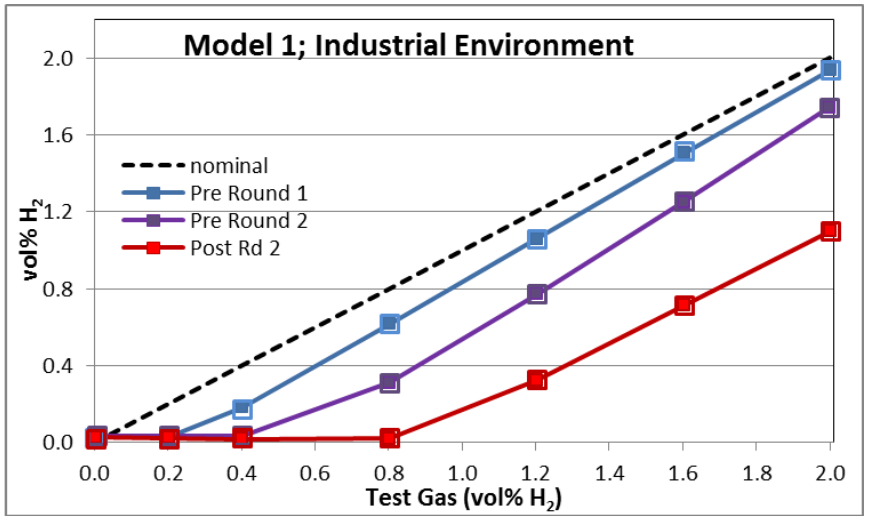
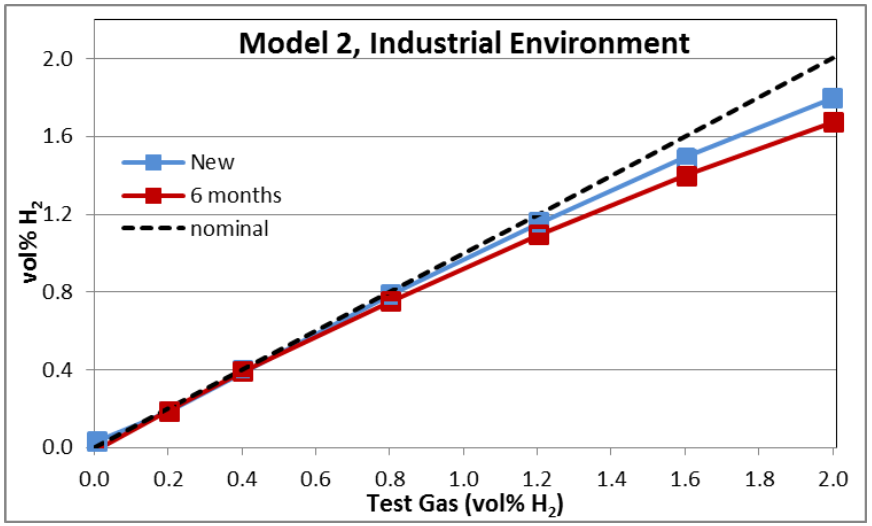
Accomplishments and Progress





- **Outcome/Significance**
  - Field performance varied significantly (Model1 vs. Model 2)
  - Laboratory performance showed no degradation (not shown)
  - "Model 2" met all requirements for applications (and is being deployed)
- **Follow-up/Status**
  - Continued support to KPA for field deployment
  - Investigation of factors that affect sensor stability
    - Behavior is not unique to this project
    - ICHS Talk ("*Impact of Environmental Parameters on Hydrogen Safety Sensor Performance*")

Accomplishments and Progress

Analyzer for Verification of Tailpipe H_2 Emissions

From the Global Technical Regulation 13
Global Technical Regulation on hydrogen and fuel cell vehicles

5.2.1.3.2. Vehicle Exhaust System

At the vehicle exhaust system's point of discharge, the hydrogen concentration level shall:

- Not exceed 4 per cent average by volume during any moving three-second time interval during normal operation including start-up and shutdown;
- And not exceed 8 per cent at any time (para. 6.1.4. test procedure).

Issues and Challenges

- Hydrogen transients must be detected in < 1 sec (implies ~ 300 ms response time)
- Measurement Range: 0 to 10 vol% (8 vol% in < 1sec pulses but average level remains < 4 vol%)
- Means of verification must exist to impose a requirement

Barriers

F. Enabling national and international markets requires consistent RCS

G. Insufficient technical data to revise standards

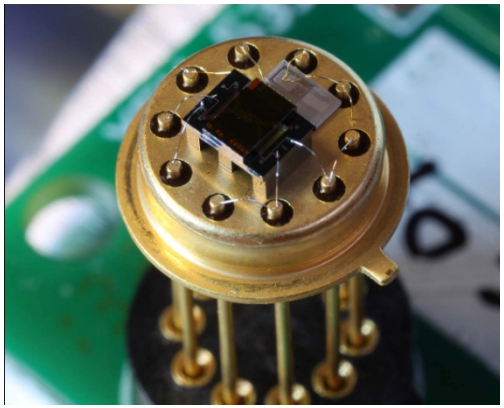
Accomplishments and Progress

Analyzer for Verification of Tailpipe H_2 Emissions

Approach 1

Mass Spectrometry

- Sampling rate: better than 5 times/sec
- Sufficient range, transportable
- Overkill (multiple component detection)
- Highly selective/unequivocal response
- Multiple models potentially available
- Expensive (~ $\$10^5$)
- Still an option for backup and verification



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[http://www.xensor.com/]

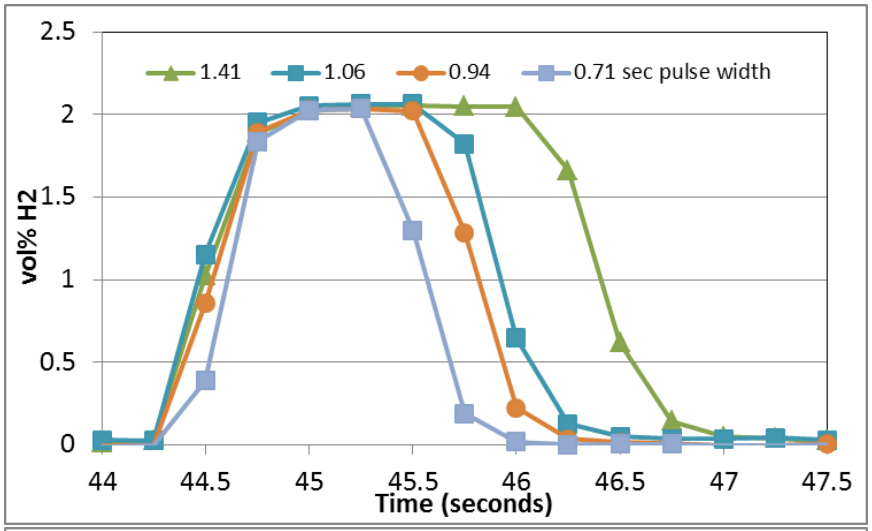
Approach 2

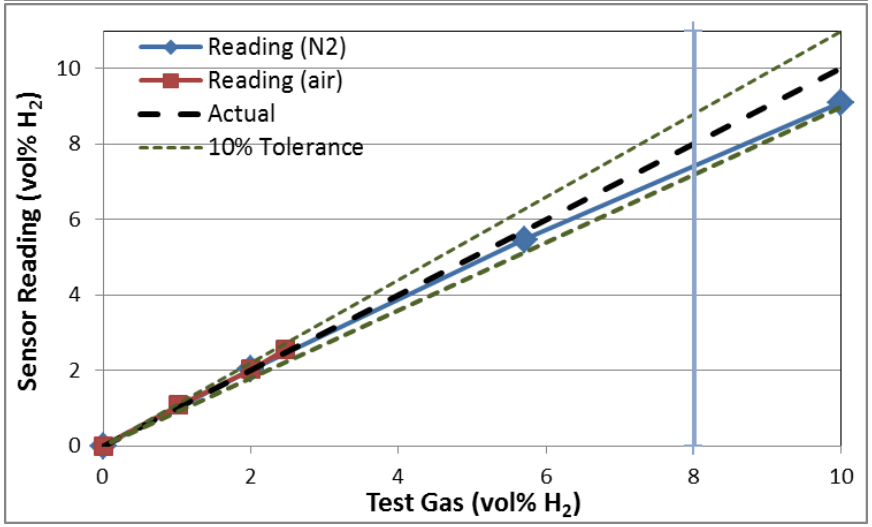
Micro TC sensor (id'd via "H2Sense")

- Response time <0.25 sec (not verified)
- Sufficient range, portable
- Portable and "simple to use" (~ $\$10^3$)
- Under evaluation
- Available in "Fast" and "Ultra-Fast" models
- Multiple manufacturers id'd

Accomplishments and Progress

Analyzer for Verification of Tailpipe H_2 Emissions





Approach 2 (TC Sensor)

Performance Summary

- Sampling rate: 4 times/sec
- Responds to gas pulses less than 1 sec
- Range up to 10 vol%
- FY 2015 milestone

Gaps and On-going Activity

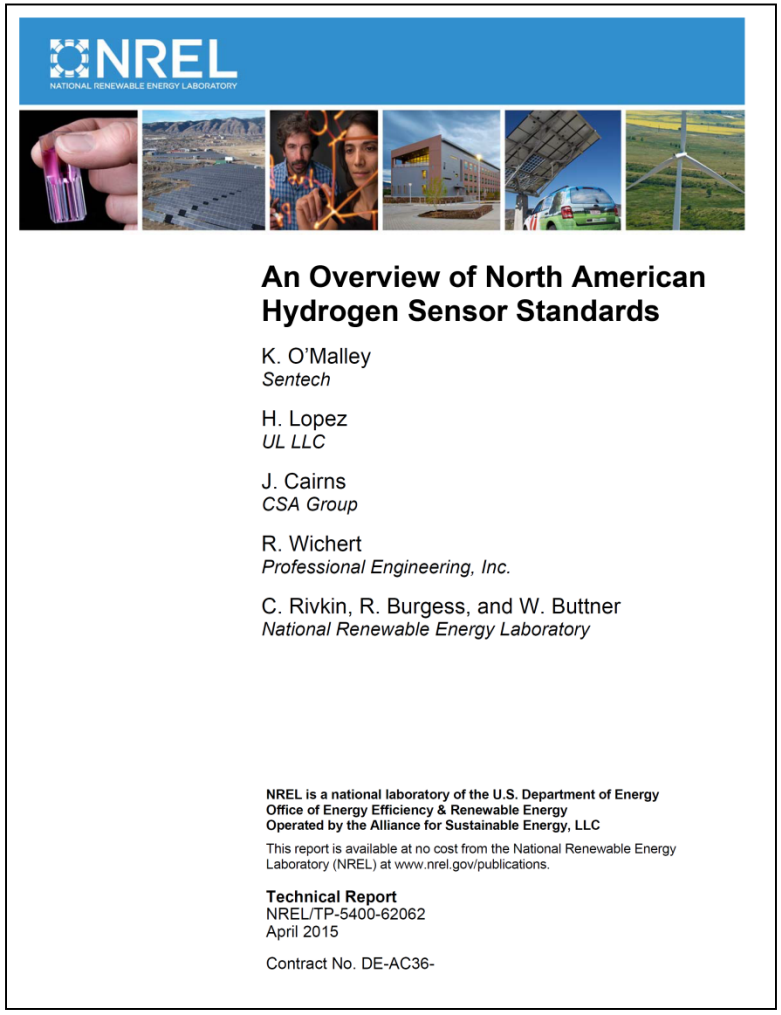
- Impact/functionality in tail pipe
- Probe design and demonstration

Relevance

- Direct verification of GTR requirements
  - DOT/NHTSA --FMVSS
  - Shared with SAE Fuel Cell Safety Task Force/OEMs
- Findings to be present at 2015 ICHS
  - With JRC-IET

Accomplishments and Progress

- **Collaborative effort among SDOs**
  - UL and CSA co-authors
  - Input from ETL, FM Global and ANSI
- **Overview**
  - Identified standard types for H2 sensors
  - Identification and description of relevant standards
  - Guidance to protect from fraudulent certification claims
  - Distinction between a code and standard
  - Sensor requirements specified in codes (IFC, NFPA 2)
  - Certification process and crucial definitions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An Overview of North American Hydrogen Sensor Standards

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National Renewable Energy Laboratory

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

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Technical Report
NREL/TP-5400-62062
April 2015

Contract No. DE-AC36-

Barrier

F. Enabling national and international markets requires consistent RCS

Accomplishments and Progress

Definitions
(as provided from SDOs)

Certification: Process by which the product design undergoes specific evaluation and testing procedures to ensure that the design meets all of the requirements detailed in a standard and is with respect to a specific standard.

Listed: Refers to the list published by a CB or NRTL of products certified to a specific standard.

Label: Mark that is displayed on products to indicate that it is certified to a specific standard

Approved

- ANSI: Refers a standard that it recognizes
- Means or authority for an AHJ to use products that are not certified (e.g., " approved by AHJ)
- Not synonymous with ***CERTIFIED****

*Not universally accepted by all SDOs (e.g., FM Global)

Photo used with permission, CSA Group

Elements of the Label

- Certification Body (CB) or NRTL marking
- Standard(s) to which product is certified
- Other qualifying information.

Accomplishments and Progress

FCH JU (BAM, JRC) and DOE (NREL) Common Call

First EU-US project with common objectives

H2Sense

Cost-effective and reliable hydrogen sensors for facilitating the safe use of hydrogen

Call:	FCH-JU-2012-1
Funding Scheme:	JTI-CSA-FCH
Grant Agreement No.:	325326
Start Date:	01/06/2013
Duration:	15 Months

New Energy World JU
fuel cells & hydrogen for sustainability

WP1: „Report on the results from independent laboratory testing and validation of commercial-off-the-shelf sensor performance"

Weidner, E.[1], Buttner, W.J.[2], Palmisano, V.[1], Bonato, C.[1], Moretto, P.[1], Burgess, R.[2], Harskamp, F.[1], Rivkin C.[2]

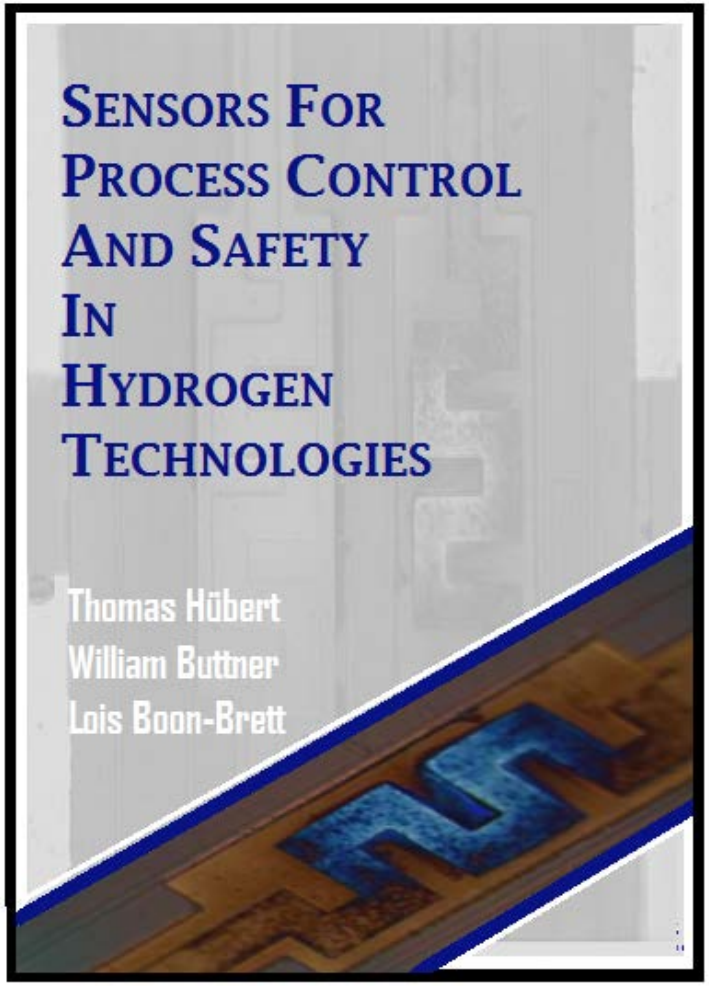
[1] Cleaner Energy Unit, European Commission – DG JRC Institute for Energy and Transport, Westerduinweg 3, (P.O.Box 2), 1755 ZG Petten, The Netherlands

[2] Transportation and Hydrogen Systems Center, National Renewable Energy Laboratory, 15013 Denver West Parkway, Golden, CO 80401-3305, USA

- Evaluate the capability of current sensors
- Ascertain how hydrogen sensors should perform in different applications
- Remove barriers which currently hinder sensor use and commercialization
- Facilitate the safe use of hydrogen by ensuring correct use of hydrogen detection devices.
- E.U. Team: BAM & JRC, working with industry under auspices of **H2Sense** (with support from FCH JU)
- U.S. Team headed primarily from NREL with support from DOE

Accomplishments and Progress

Coming soon from the CRC Press (in press)



Authors

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- Valerio Palmisano, formerly JRC
- Ulrich Schmidtchen, BAM
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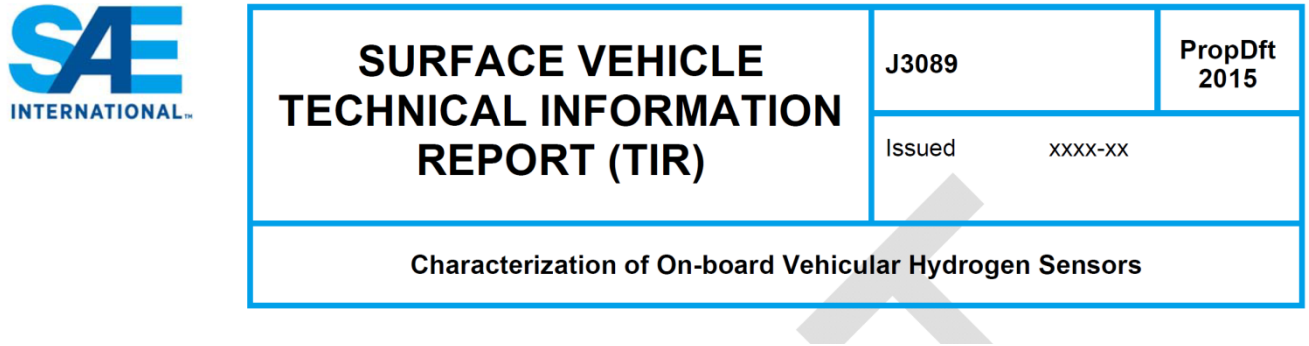
Accomplishments and Progress



- Sensor Laboratory active participant in SAE Fuel Cell Safety Task Force (FCSTF)
- Develop guideline for qualifying sensors considered for automotive applications
- In Process with draft document for review June 10, 2015 at SAE FCSTF meeting

SAE J3089 IS NOT A STANDARD

- provides guidance and proposed test methods for hydrogen sensors –

There are no pass/fail criteria

It does not dictate that sensors are required on-board vehicles

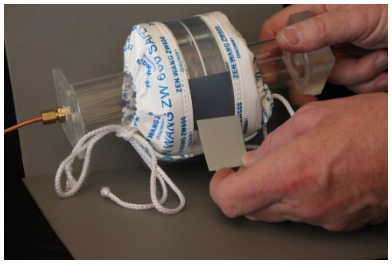
Collaborations—Private Organizations

Deployment (Hydrogen Safety)

- **KPA:** (CRADA) NREL provided expert guidance on hydrogen sensor technology in support of KPA integrated safety system
- **Ford Motor Company** (NDA)
- **Parker Aerospace:** (TSA) NREL activity to include quantitative assessment of hydrogen sensors; investigate failure modes; develop mitigation strategies
- **Other**: (NDA signed, TSA proposed)--proprietary customer

Technology Development/verification

- **Element 1:** (MOU, Subcontract) Colorimetric indicator to be tested on NREL operations (deployment)



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http://www.elem1.com/

Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

- **(Project Weaknesses)** This project could use more direct collaboration with automotive OEMs.
- **(Recommendations)** It is suggested that less attention be spent on vehicle sensors and more on stationary applications.

It is the philosophy of the sensor laboratory to try to balance finite resources to meet the broadest needs of the hydrogen community. With that said, the current activity of the sensor laboratory has direct collaborations with vehicle OEMs as well as for support of stationary application. Furthermore, the PI for the sensor laboratory is now a formal member of the SAE Fuel Cell Safety Task Group and is a lead author for the development of TIR SAE J3089: Characterization of On-board Vehicular Hydrogen Sensors.

Accomplishments and Progress: Responses to Previous Year Reviewers' Comments

- **(Project Weaknesses)** It would be good to see this project reach out to the Asian hydrogen community and establish an appropriate collaboration.

The activity of the sensor laboratory has certainly been more Euro- and North America centric and it is recognized that more direct interaction with the Asian community would be mutually beneficial. Although resources are limited, this is being addressed. The sensor laboratory has a project with Toyota (albeit N. American). Furthermore participation on the SAE Fuel Cell Task Force has resulted in direct interaction with JARI (who provided good input into the proposed TIR). Finally, the upcoming ICHS meeting will provide an opportunity for active outreach to the Asian hydrogen community.

Remaining Challenges and Barriers

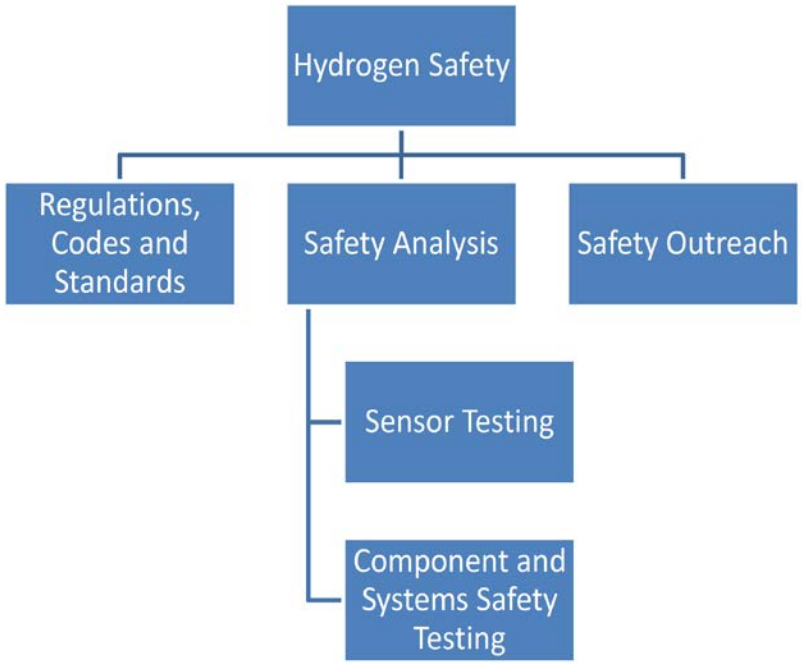
Hydrogen Safety Sensors:

- **Stakeholder acceptance/perception:** Although less now than in the past, there remains a lack of acceptance on the use of safety sensors, but often coupled with the hypothetical caveat "or alternate means".
- **Low maintenance sensors/lifetime:** Sensor maintenance (calibration, replacement, and even out-of-the box in spec performance) remains an issue. Mitigating impact of poisons and lengthening calibration duty cycles is essential to improve end-user acceptance.
- **Response time:** Some application of safety sensors require a response time of 1 sec; this has remains elusive, although a TC platform can meet this requirement under certain conditions. Standardize RT does not exist

System Operations

- **Process control:** Potential for hydrogen system operations (e.g., intelligent control of anode gas streams) via real-time monitoring.

Future Work: The NREL Hydrogen Sensor Multiyear Plan



Manufacture/Developer Support

- Sensor performance validation
- Developmental technologies support
- Wide area monitoring/distributed sensors
- Process control/hydrogen
- Process control/fuel quality sensors
- Field deployment test

End-User Support to Support Deployment

- Auto-calibration
- Guidance on deployment / placement
- DOT and the GTR on hydrogen vehicles
- Barriers to sensor certification and impacts
- Delivery
- Support of NREL component testing

ESIF – Energy Systems Integration Facility

New NREL facility includes the sensor lab, components lab, high pressure test lab, and infrastructure test sites (e.g., fueling station, Energy Systems Integration Laboratory, ESIL)

Proposed Future Work

FY15

- Continued support of Repair Garage deployment (KPA)
- Sensor support of NREL Component testing
- Continued assessment, with DOT-NHTSS of H2 vehicle FMVSS sensor requirements, update text of GTR
- “Sensors for Process Monitoring and Safety in Hydrogen Technology”
- Continued investigation of WAM

FY16

- Support implementation of other infrastructure (e.g., tunnels)
- Sensor lifetime studies and mitigation strategies
- Complete review and update on WAM

Summary

Relevance: Sensors are a critical hydrogen safety element and will facilitate the safe implementation of the hydrogen infrastructure.

Approach: NREL Sensor Laboratory tests and verifies sensor performance for manufacturers, developers, end-users, and SDOs

Accomplishments & Progress: NREL's R&D accomplishments have supported developers, industry, and SDOs by providing independent third party assessment of performance

Collaborations: Collaboration with other laboratories (JRC, universities, private industry) has leveraged NREL's success in advancing hydrogen safety sensors.

Proposed Future Work: NREL will support hydrogen deployment and the proper use of hydrogen sensors. NREL will support the development of improved methods to verify fuel quality. NREL will continue to work with SDOs to revise documents, when required.