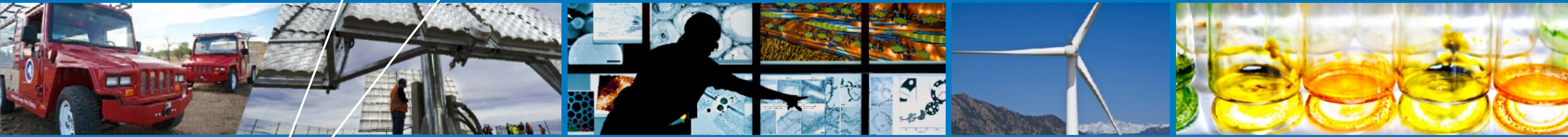
Hydrogen Sensors



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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.H2incidents.org]
  - "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 will be referenced in IFC

Hydrogen dispenser equipped with wall-mount and internal sensors

Purpose of Sensor Testing Laboratory

- Provide independent assessment of hydrogen sensor performance
- Interact with manufacturers to improve sensor performance to meet targets (e.g., ISO 26142, DOE, specialized applications)
- Test/validate new sensor R&D
- Support hydrogen sensor codes and standards development (national and international)
- Support end-users (deployment)
    - o "Topical Studies"—information on sensor use
    - o Direct collaborations with the H_2 Community
- NREL Sensor laboratory does NOT certify (but can provide assistance)
- 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

Sensor Testing Laboratories—Generalized Capability

- Sensor test facilities at BAM, IET-JRC, and DOE-NREL
  - Laboratory level MOA between NREL and IET
  - Topical Studies since 2008
- Sensor Test Facilities capability
  - Multiple Sensors
  - Controlled and monitored T, P, RH
  - Controlled and monitored gas parameters (flow, composition)
  - Fully automated control and data acquisition
  - RRT verified facility data quality (NREL-IET)
- Specialized testing
  - Long term life test—ambient and harsh condition (e.g., T, RH, Chemical)
  - Response Time (IET) and ultra-fast response time (BAM) Capabilities

Sensor Testing Facility (SenTeF) at the IET

NREL NATIONAL RENEWABLE ENERGY LABORATORY

BAM Federal Institute for Materials Research and Testing

European Commission

iet Institute for Energy and Transport

EU (FCH JU) and US-DOE Common Call

From the 2012 FCH JU Implementation Plan

- Cross-cutting Programs: *Assessment of commercially available hydrogen safety sensors in terms of e.g. performance and cost-effectiveness for near-term applications. This study will benefit from international collaboration with the US DoE research programme.*

Partners

- EU: BAM, JRC, and 4 Industrial Partners (FCH-JU support) H2Sense: "*Cost-effective and reliable hydrogen sensors for facilitating the safe use of hydrogen*"
- US: NREL Sensor Laboratory (through DOE support)
  - Keynote Speaker at H2Sense H_2 Sensor workshop, telecoms, program reviews, sensor evaluations, final report, and future work plans.

New Energy World JU
fuel cells & hydrogen for sustainability

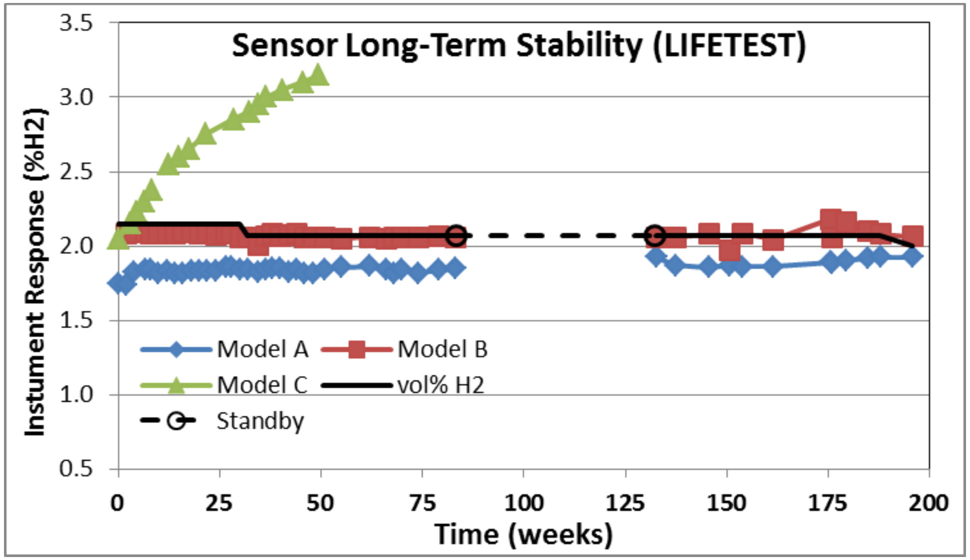
H2Sense

Features of the common call

- Knowledge transfer on the state-of-the-art of sensor technologies.
- Cross-fertilization of know-how on correct sensor use (including placement).
- Expanded pool of input into the identification of critical gaps in current sensing technologies.
- Increased awareness of mutual markets and applications for hydrogen sensors including exchange of knowledge on codes and standards for their use.
- Identification of common barriers to commercialization of hydrogen sensors and pooling of ideas for innovative solutions to overcome these barriers.

Field performance of sensor performance (lifetime)

- Sensor lifetime remains concern
  - Outright failure
  - Sensor drift beyond specification (more common)
- Premature failure in the field still observed--Initiated study for cause
  - Impact of interferents/poisons (as per ISO 26142)
  - Impact of deployment conditions



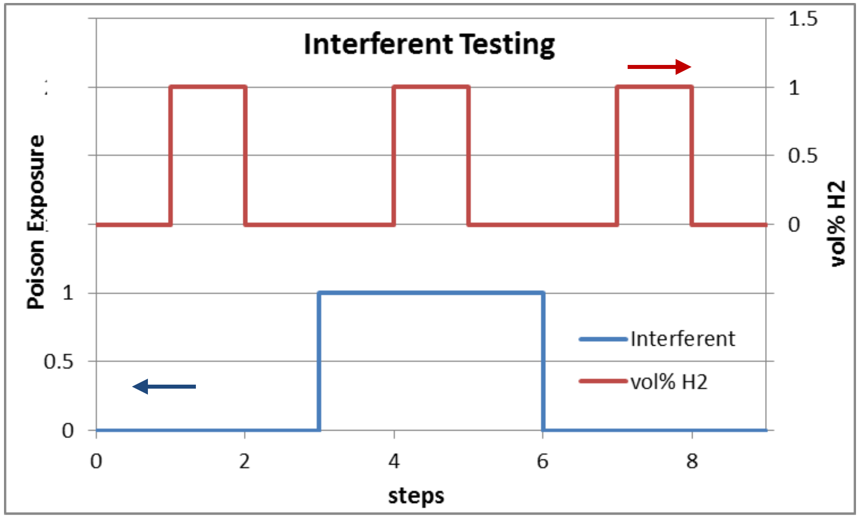
Laboratory Testing

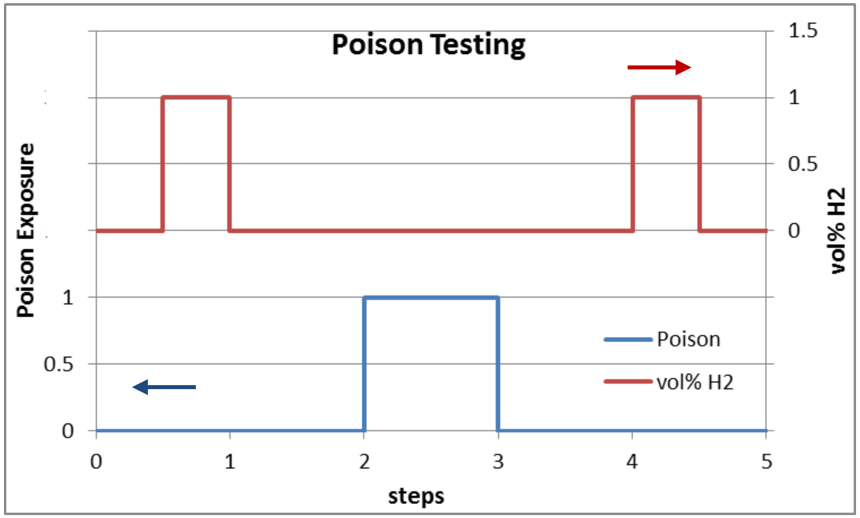
Sensor Performance (life test)

- Up to 4 years continuous operation (on-going)
- Controlled T, RH, clean chemical environments, ambient P.
- Periodic challenge to 2 vol% H_2
- Several sensors remain within manufacturer specification
- Some models show immediate degradation

Impact of Interferants/Poisons

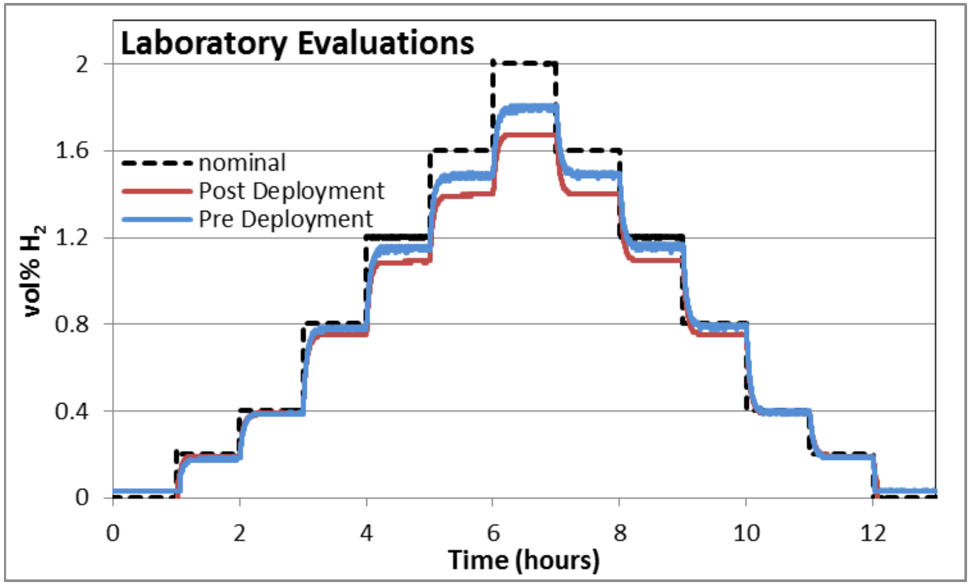
- Impact of interferent (in air and air/H2)
  - Based on ISO 26142
  - Temporary impact on baseline and/or span
  - Minimal impact observed on tested sensors (except CGS, TC)
- Impact of "poisons"
  - Based on ISO 26142
  - Permanent impact of sensor (especially span)
  - Minimal impact observed on multiple platforms (none on span!)





Impact of Field Deployment

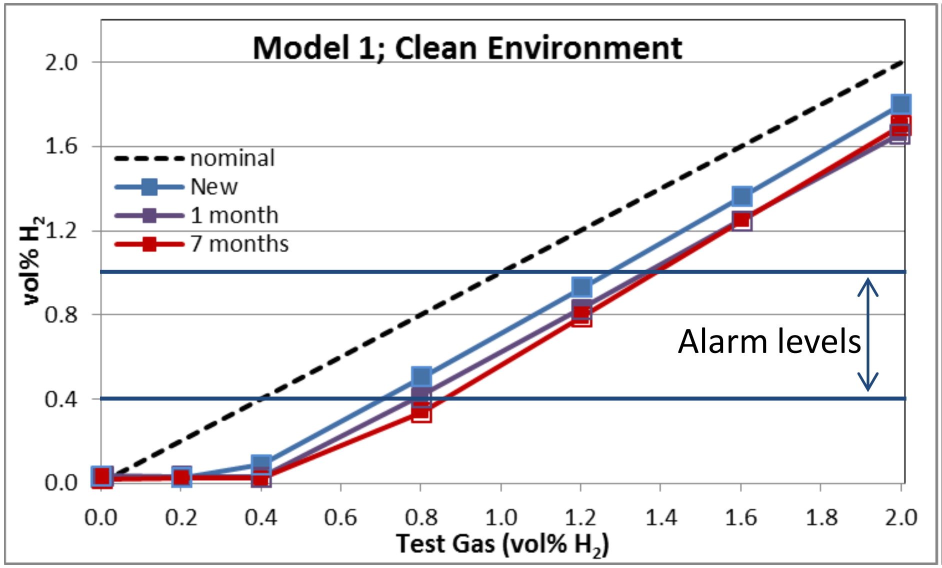
- Impact of field deployment
  - 6 to 7 months deployment
  - 4 sensor models, multiple units
  - Part of actual qualification study
- Multiple deployment conditions
  - "Clean" laboratory (regulated T, RH, chemical environment)
  - Industrial Environment (regulated T) but harsher chemical environment
- Evaluations
  - Periodic field challenges (1 and 2 vol% H_2)
  - Laboratory Testing performed prior to and following deployment

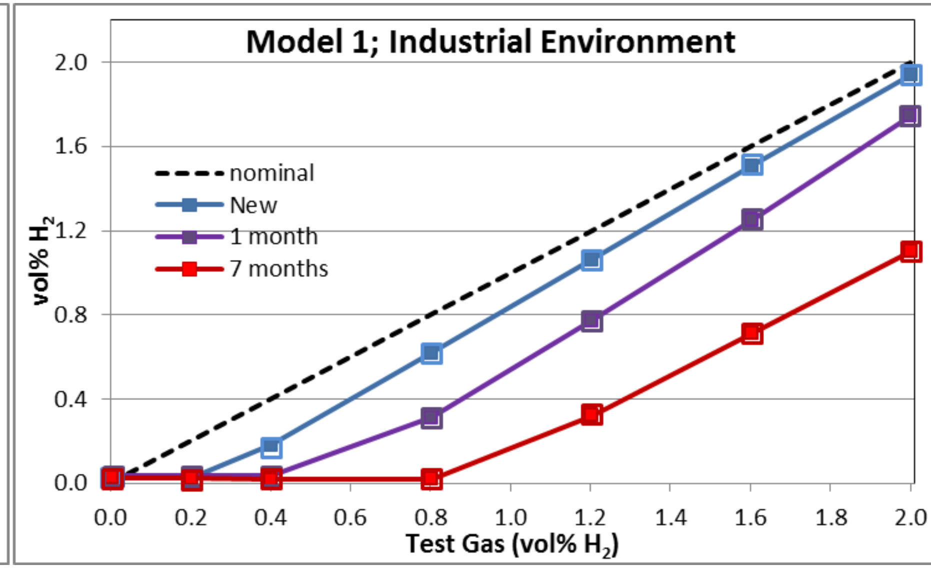


Laboratory Testing

Sensor evaluations were performed prior to and following extended deployment (up to 7 months).

"Field Performance" of Model 1



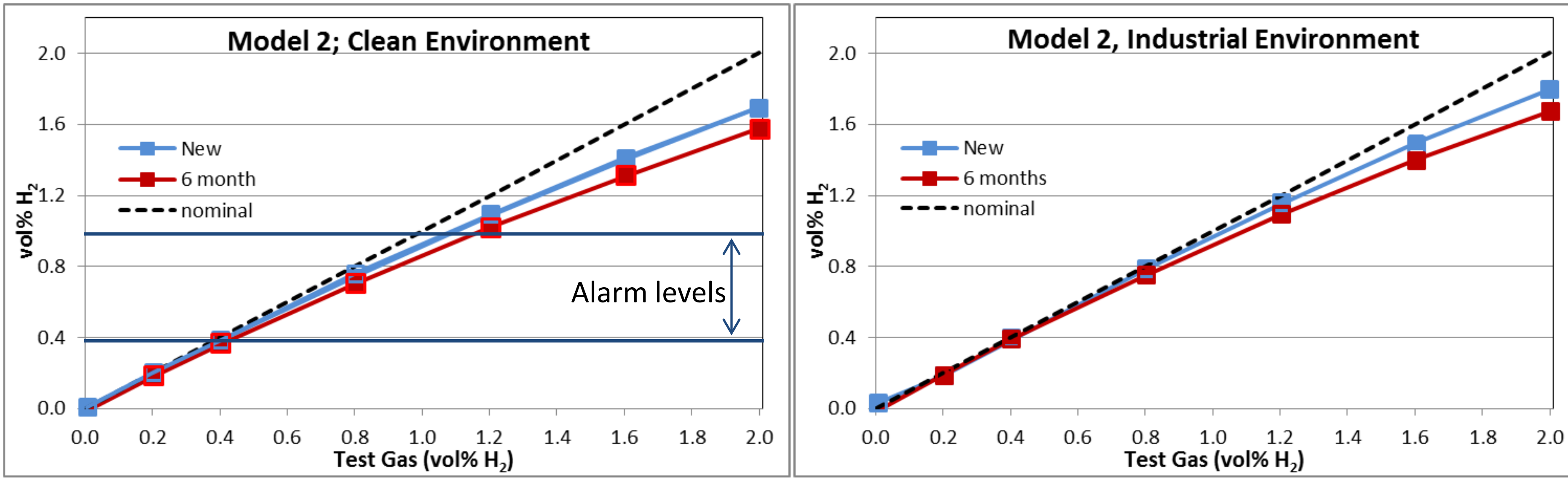


Impact of Field Deployment

- Platform type: EC
- Two step field deployment: 1 month + 6 months
- Stable response in laboratory (left)
- Rapid degradation in industrial environment (right)

Results indicative of specific model and not platform type

"Field Performance" of Model 2



Impact of Field Deployment

- Platform type: CGS
- Field deployment: 6 months
- Stable response in laboratory (left)
- Stable in industrial environment (right)

Results indicative of specific model and not platform type

Conclusions—summary, gaps and looking forward

- Deployment Studies
  - Sensor failure often shows up quickly
  - Sensor stability is often dictated by the deployment conditions.
  - Qualification for application necessary
  - Mitigating strategies under development
- Impact of interferents and poisons
  - Test protocols may be inadequate
- Sensors are still expensive
  - Economy of scale production-- not feasible with current/projected market
  - Alleviated with common recommended metrics
  - Advanced approaches (WAM)

THANK YOU

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Coming Soon

Book: "Sensors for Process Monitoring and Safety in Hydrogen Technology", T. Hübert, W. Buttner, L. Brett, E. Weidner, et al., CRC Press, projected publication date: Q1 2015.