National Renewable Energy Laboratory
Innovation for Our Energy Future

2010 DOE Annual Merit Review Component Standard Research & Development

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National Renewable Energy Laboratory Hydrogen Technologies & Systems Center

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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**
- *End date*: **September, 2012**
- Multi year DOE RD&D target date
- *Percent complete*: **50%**

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 component certification *(M,N)*

BUDGET

- Funding in FY09:
  $600K (+250K capital)
- Funding for FY10*:
  $ 400K

* FY10 efforts include contract funding committed in FY09

PARTNERS

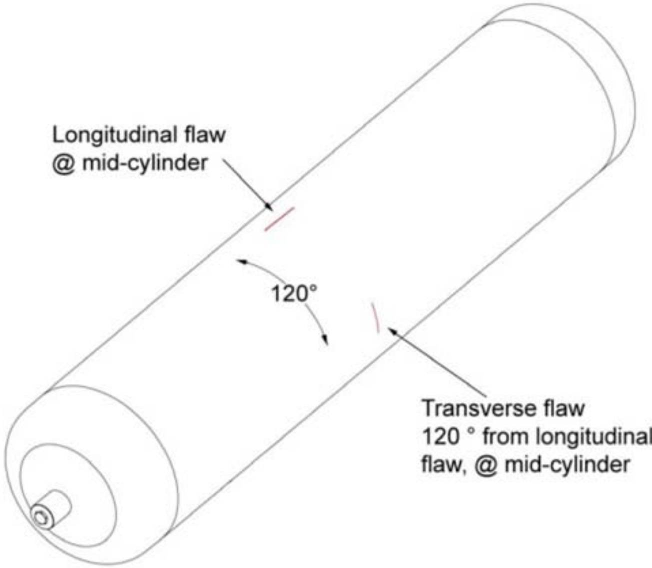
- Industry (Component Manufacturers, *Automotive OEMs, Gas Suppliers)*
- Laboratories /Universities (JRC, BAM, NIST, NASA, Battelle, Powertech, JARI, IIT, IEEE)
- Codes & Standards Organizations (SAE, CSA, ASME, ISO, UL, NFPA, ANSI)

Relevance – Hydrogen Infrastructure Technology Gaps

Hydrogen Component Requirements	Technology Gap
Tanks *ASME Boiler and Pressure Vessel Code* New addition to test standard for composite overwrapped pressure vessels	High pressure performance testing being developed to insure survivability with flaw added to exterior surface requires testing to be used as basis for code language
Interface *SAE J2601 Fueling Protocol* New non communication fill tables for hydrogen vehicle fueling are designed to insure temperature limits are not exceeded	Tables developed by thermodynamic modeling need to be validated with actual performance test data
PRD *CSA HPRD1 Pressure Relief Device* New performance based standard for temperature activated pressure relief device	Hydrogen service suitability test, designed to insure PRD operation is not compromised by hydrogen effect on materials, requires validation testing
Safety Sensors *Hydrogen leak detection NFPA 52 section 9.4.7.4* requires use of hydrogen leak detection for safe alarm and shutdown	DOE 2007 sensor workshop identified hydrogen safety sensor performance gaps relative to end user needs

ASME BPV Flaw Testing

High pressure testing of vessel survivability with longitudinal and transverse flaw to be defined in ASME BPV code case



Relevance: New ASME code case requiring testing to be used as basis for code language

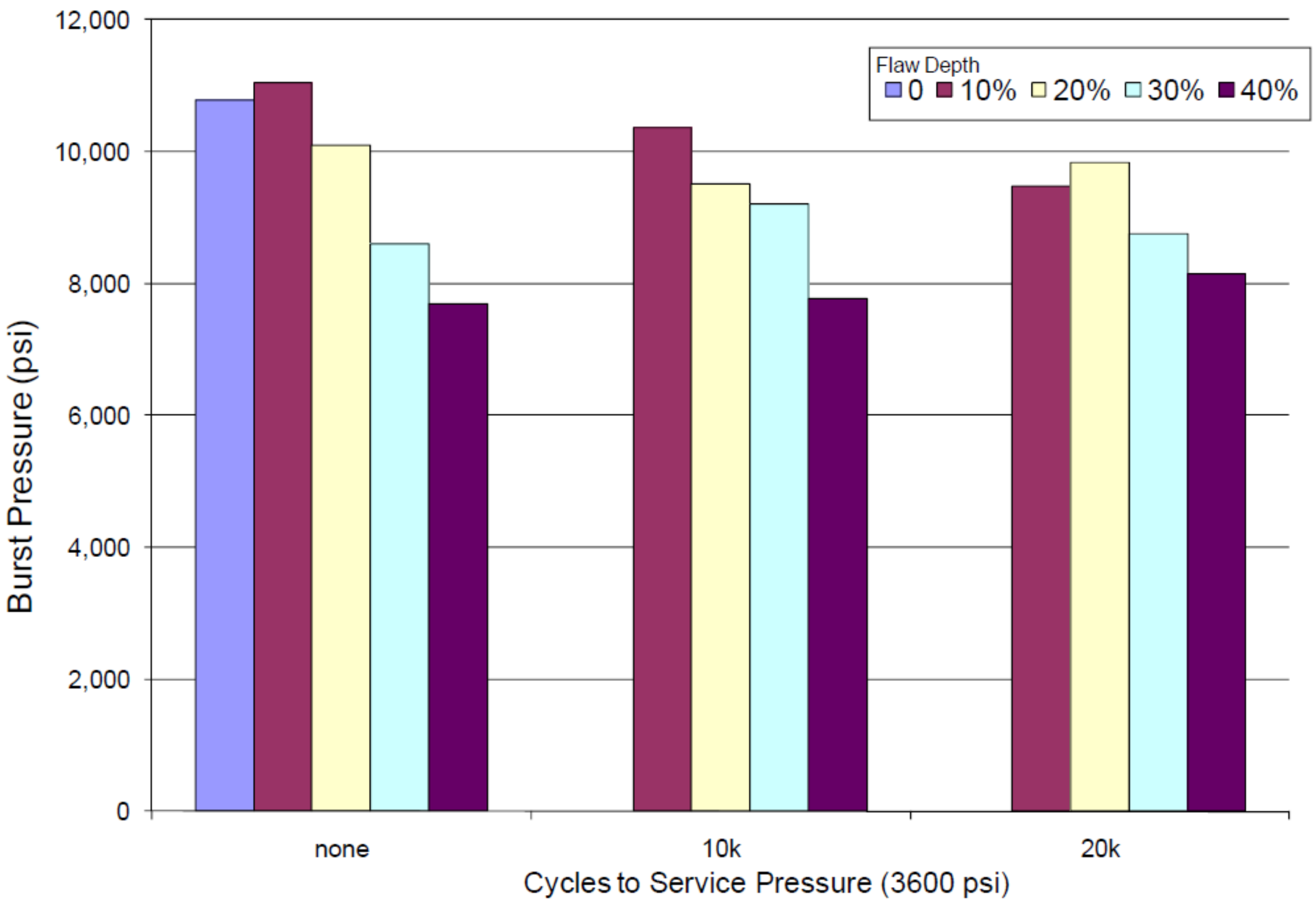
Approach: NREL subcontract with ASME to complete flaw testing

Results: Final report completed 23 October 2009

Collaboration: ASME, Lincoln Composites, BPV Code committee

Future: Flaw testing complete, continue to work with ASME in identifying R&D gaps

ASME BPV Flaw Test Results



Even with the deepest flaw, which is deeper that any typically found in service, the resulting burst margin would still allow for safe operation of the pressure vessel over a period of time

ASME Flawed Cylinder Testing Final Report, Figure 8-2
Burst pressure versus cycling and depth of flaw

SAE J2601 fueling protocol testing

SAE J2601 fueling tables in draft document were generated by thermodynamic modeling, requiring validation testing

A-70 1-7kg	Actual Fueling Duration (min) Add intermediate leak check times: up to 10 sec after every 25MPa increase in fueling pressure										
	Initial Tank Pressure, P_0 (MPa)										
Ambient Temperature, T_{amb} (°C)	2	5	10	15	20	30	40	50	60	70	> 70
> 50	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling
50	6.3	6.0	5.5	5.1	4.6	3.7	2.8	1.9	1.0	0.2	no fueling
45	4.6	4.4	4.0	3.7	3.4	2.7	2.1	1.4	0.8	0.1	no fueling
40	3.6	3.5	3.2	2.9	2.7	2.1	1.6	1.1	0.6	0.1	no fueling
35	3.1	2.9	2.7	2.5	2.2	1.8	1.4	0.9	0.5	0.1	no fueling
30	2.6	2.5	2.3	2.1	1.9	1.5	1.1	0.8	0.4	0.0	no fueling
25	2.5	2.4	2.2	2.0	1.8	1.4	1.1	0.7	0.3	no fueling	no fueling
20	2.5	2.4	2.2	2.0	1.8	1.4	1.0	0.7	0.3	no fueling	no fueling
10	2.5	2.4	2.1	1.9	1.8	1.4	1.0	0.6	0.2	no fueling	no fueling
0	2.4	2.3	2.1	1.9	1.7	1.3	0.9	0.5	0.1	no fueling	no fueling
-10	2.4	2.3	2.1	1.8	1.6	1.2	0.8	0.4	no fueling	no fueling	no fueling
-20	2.4	2.2	2.0	1.8	1.6	1.1	0.7	0.3	no fueling	no fueling	no fueling
-30	2.3	2.2	2.0	1.7	1.5	1.1	0.6	0.2	no fueling	no fueling	no fueling
-40	2.3	2.2	1.9	1.7	1.5	1.1	0.6	0.2	no fueling	no fueling	no fueling
< -40	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling	no fueling

J2601 Table G-2 fill times for -40 C pre-cooling

***Relevance**:* New SAE fueling standard requiring validation testing

***Approach**:* NREL subcontract with SAE to complete validation testing

Results: Final report completed 16 March 2010

***Collaboration**:* SAE, Powertech Labs, SAE interface committee

Future: Fueling protocol testing complete, continue to work with SAE in identifying R&D gaps

SAE J2601 fueling protocol testing

Test results were shared with the SAE Fuel Cell Interface Working Group and it was determined that models and fueling tables required no further modification prior to publication of the SAE TIR J2601 standard

Pressure Class	Pre-Cooling Temp *	Tank Capacity	Ambient Temp	Tank Initial Temp	Tank Initial Press	Tank Type	Results Actual Results Theoretical SOC (State of Charge)
70MPa	-40 C	< 6kg	30 C	30 C	15 MPa	4.7 kg IV	SOC = 89.6%, 88%
70MPa	-40 C	< 6kg	30 C	30 C	15 MPa	1.4 kg III	SOC = 89.5%, 87%
70MPa	-40 C	> 6kg	30 C	30 C	15 MPa	9.8 kg IV	SOC = 93.0%, 90%
70MPa	-40 C	> 6kg	30 C	30 C	15 MPa	1.4 kg III	SOC = 89.8%,92.6%
35MPa	-20 C	< 10kg	30 C	30 C	5 MPa	1.0 kg III (35MPa NWP)	SOC = 94.7%, 98%
35MPa	-20 C	< 10kg	30 C	30 C	5 MPa	3.0 kg IV (35MPa NWP)	SOC = 96%, 94.9%

SAE J2601 Confirmation Testing Final Report
Results of the Expected Fueling Case tests Table 6: Expected Fueling Case Results

CSA HPRD1 hydrogen service suitability testing

Scope of work

Task 1 Perform HPRD section 7.6 hydrogen service suitability test on (3) samples of (3) designs, i.e. (9) total PRD's

Task 2 Cycle testing to failure on (3) PRD's, one from each design

Task 3 Produce (3) surrogate designs using non-compatible material and perform section 7.6 testing to show capability to fail poor design

Task 4 Post test metallurgical evaluation

Relevance: New CSA HPRD1 standard requiring validation testing

Approach: NREL subcontract with SAE to complete validation testing

Results: HPRD components purchased and testing started

Collaboration: CSA, SAE, Powertech Labs, HPRD1 standard committee

Future: HPRD testing scheduled to be completed by end of FY2010, continue to work with CSA HPRD1 committee in identifying R&D gaps

Relevance— *Hydrogen Safety Sensors*

- *NFPA 52 section 9.4.7.4* requires use of hydrogen leak detection for safe alarm and shutdown, comparable code requirements exit for international marketplace
- DOE 2007 sensor workshop identified hydrogen safety sensor performance gaps relative to end user needs
- European Commission has also identified hydrogen safety sensor gaps and is funding the JRC's Institute for Energy to perform R&D evaluation of sensor performance.
- NREL and JRC are collaborating on test protocols and are performing round robin testing in order to expedite our mutual goal of characterizing the sensor market and supporting sensor commercialization
- ISO 26142 draft standard protocols are being developed based on the joint efforts by NREL , JRC, JARI and others

Approach – Safety Sensors

- 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

NREL Test Apparatus

- FY09 Apparatus fully assembled
- FY10 test protocol development
- Capabilities
  - Environmental system controls for temperature, pressure and relative humidity
  - Automated control and data acquisition
  - Mass spectrometer for independent gas analysis

Technical Accomplishments and Progress

NREL/JRC Round Robin Testing

Test Protocol Developed for Lab to Lab Data Comparison

Three technologies selected for round robin testing, each laboratory starts with three sensors of each type

- Round 1 - full test sequence each sensor
- Round 2 – exchange sensors and repeat full test sequence
- Round 3 – Inferent/poison test and long term stability testing

Technical Accomplishments and Progress

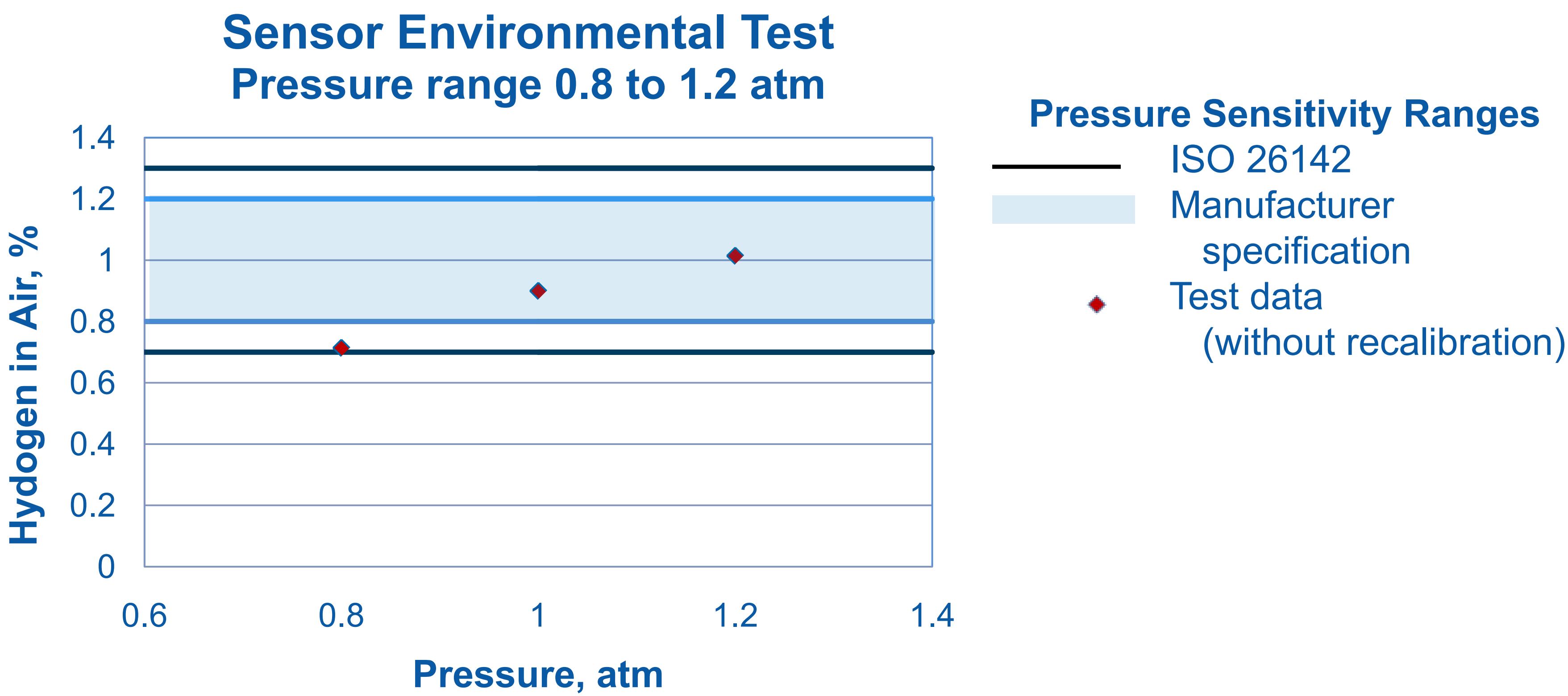
NREL/JRC Round Robin Testing

Test Sequence Developed for Lab to Lab Comparison

- Short term repeatability test – exposure to 0.2, 1.0 and 2.0 % hydrogen in air, repeated nine times
- Pressure test – hydrogen exposure at 0.8, 1.0 and 1.2 atmospheres
- Temperature test – hydrogen exposure at -20°C, 0°C, 25°C, 50°C and 85°C
- Humidity test – hydrogen exposure at 5%, 25%, 50% and 85% relative humidity
- Linearity test – Exposure to progressively ascending then descending hydrogen exposures in air

Technical Accomplishments and Progress

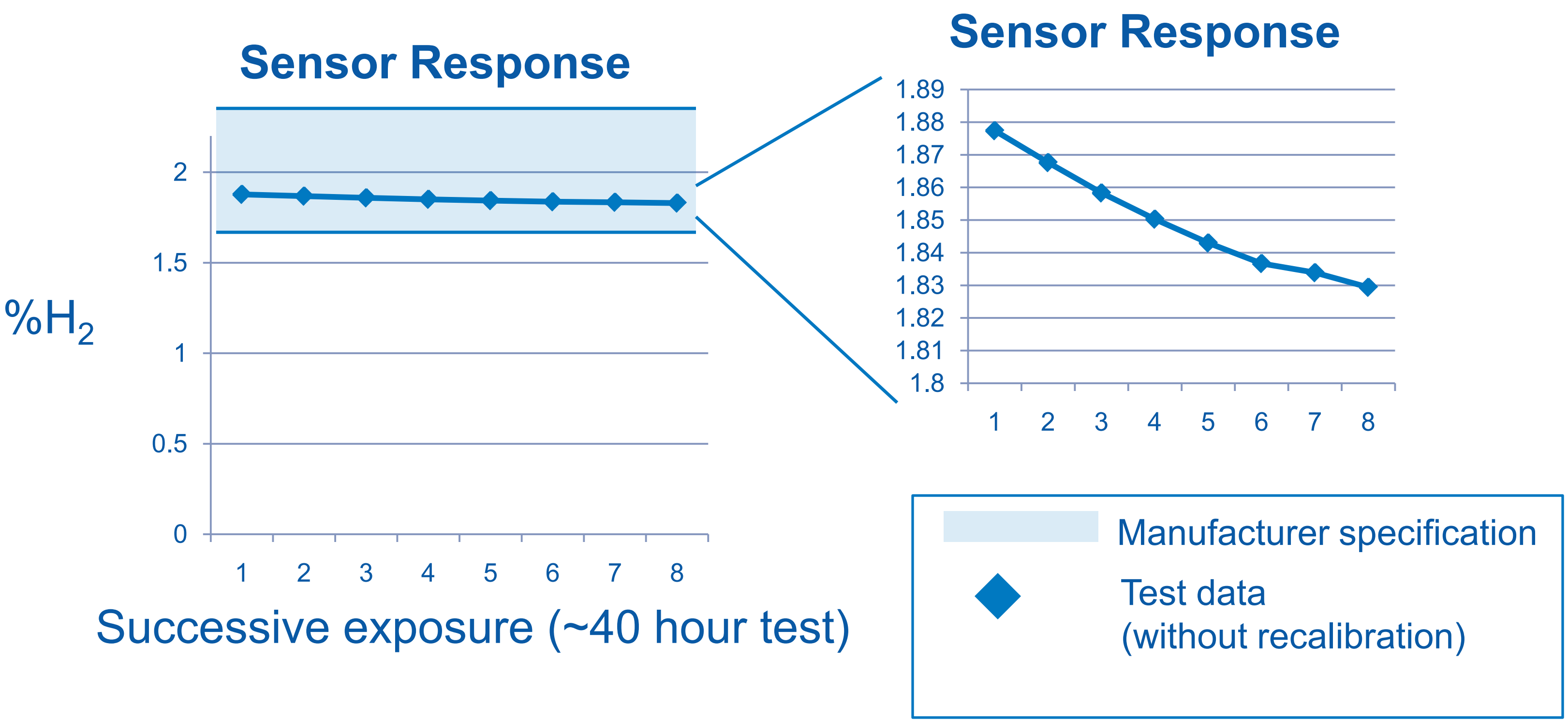
NREL/JRC Round Robin Testing, Environmental Effects



Sensor output varies with changes in atmospheric pressure, sensor response would require re-calibration over the tested pressure range

Technical Accomplishments and Progress

NREL/JRC Round Robin Testing, Exposure Effects



Sensor output varies with successive exposure to 0-2% hydrogen in air, test protocols produce accumulative stress

Collaborations

Sensor Manufacturers

- More than140 manufacturers identified so far, contacts with 30%
- Intelligent Optical Systems test support for product development cycle
- 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

- NIST (National Institute for Standards and Technology), NASA (interagency collaboration for hydrogen fuel cell stationary power), Battelle, Powertech Labs, IIT(Illinois Institute of Technology, sensor lab), IEEE (Institute of Electrical and Electronic Engineering, hydrogen release from batteries)

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, draft 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
- Joint round robin test program and NHA conference presentation

Federal Institute for Material Research and Testing

- Government laboratory in Berlin, Germany, also known as BAM (Bundesanstalt für Materialforschung)
- Collaboration through ISO and Hysafe

JARI (Japanese Automotive Research Institute)

- Collaboration through joint efforts on ISO 26142 standard

NREL/JRC collaboration meeting, Petten, March 2010

Proposed Future Work - Component R&D

Continue to develop component level hydrogen codes and standards by identifying gaps and working with industry to close those gaps by providing national laboratory R&D support

High Pressure Components

- NASA collaboration for tank level stress rupture testing
- Conduct strength of materials modeling for safety factor prediction *HPRD*
- Evaluation of HPRD repeatability and reliability
- Long term creep study to determine eutectic material activation time and reliability at different exposure temperatures

Safety Sensors

- Complete round robin evaluation with JRC lab
- Publish composite data for five sensor technologies, to be used by manufacturers in market evaluation and end user in sensor applications
- Conduct sensor placement analysis by using CFD model code, previously validated in NREL garage release study

Conclusions

- NREL component R&D efforts designed to close technology gaps
- NREL subcontracts foster development of infrastructure for component testing, development and certification
- Development of new and improved standards will remove roadblocks to technology commercialization
- Improved hydrogen safety sensors will facilitate installation and operation of stationary hydrogen production, storage and dispensing hardware