

Overview of the DOE hydrogen safety, codes and standards program part 3:

# **Advances in Research and Development to Enhance the Scientific Basis for Hydrogen Regulations, Codes and Standards**

**Brian Somerday**

Sandia National Laboratories



# Outline

- **Hydrogen Behavior**

- Bob Schefer, Bill Houf, Bill Winters, Greg Evans, Mark Grothe, Isaac Ekoto, Adam Ruggles, Ethan Hecht

- **Quantitative Risk Assessment**

- Jeff LaChance, Katrina Groth, Chris LaFleur, Alice Muna

- **Hydrogen Compatibility of Materials**

- Brian Somerday, Chris San Marchi, Jeff Campbell, Ken Lee, Joe Ronevich

- **Hydrogen Fuel Quality**

- Rangachary Mukundan, Tommy Rockward

# Fuel Cell Technologies Programs at the National Laboratories



*Providing the science and engineering to accelerate the deployment  
of clean and efficient hydrogen technologies*

**Science-based regulations, codes and  
standards ensure technology requirements  
are consistent, logical and defensible**

Hydrogen and fuel cell  
systems enable  
dramatic reductions in  
both GHG emissions  
and foreign oil  
dependence



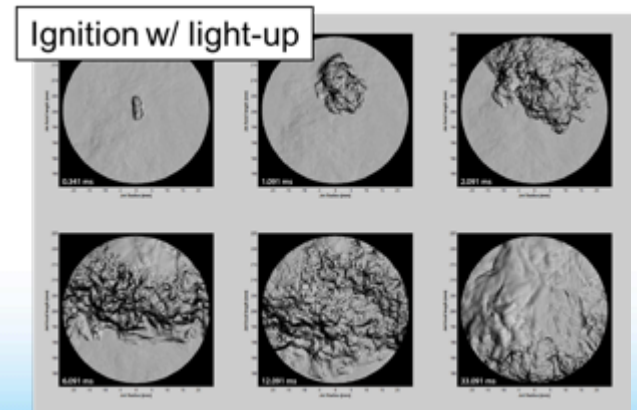
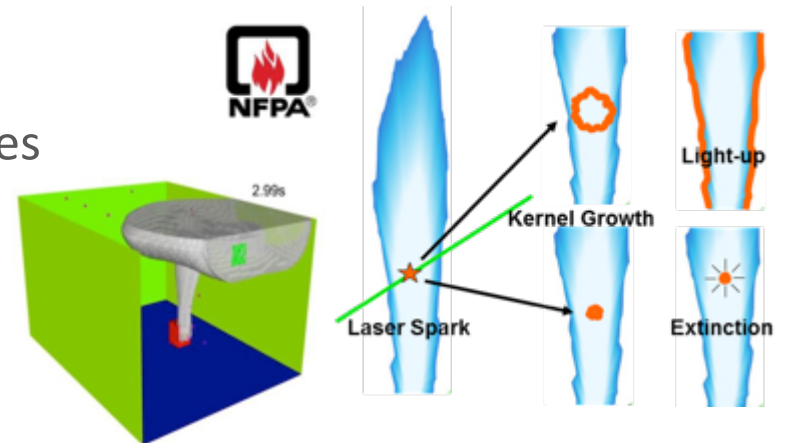
# Accelerating deployments with fundamental understanding of *hydrogen behavior* and *quantitative risk assessment (QRA)*

## Goal

Facilitate the safe use of hydrogen technologies by understanding and mitigating risk

## Demonstrated Impact

- Enabling the deployment of refueling stations by developing science-based, risk-informed decision making processes for specification of safety distances in existing code
- Sandia's analysis has enabled the indoor use of fuel cell powered vehicles



# Behavior and risk models can be integrated to enable consistent (and accepted) risk assessment process

risk



**Develop integrated methods and algorithms**

for enabling consistent, logical and defensible QRA

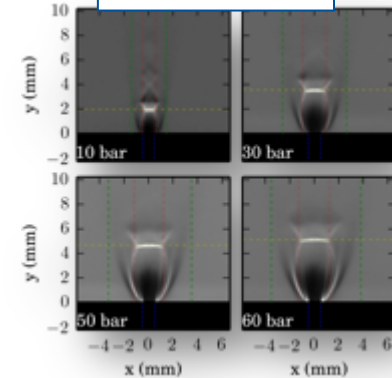
application



**Apply quantitative risk assessment techniques**

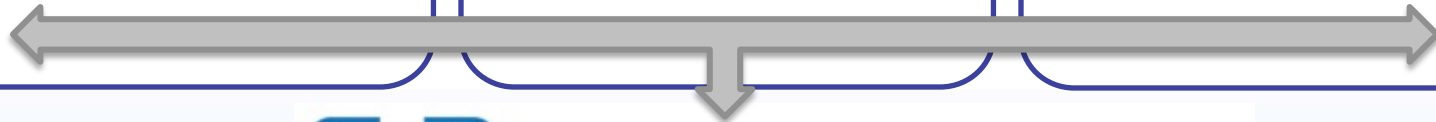
in real hydrogen infrastructure and emerging technology

behavior



**Develop and validate scientific models**

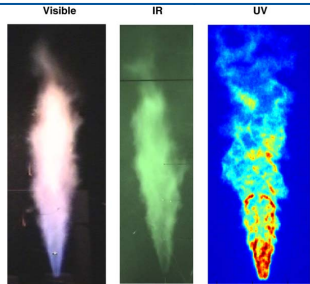
to accurately predict hazards and harm from liquid releases, flames, etc.





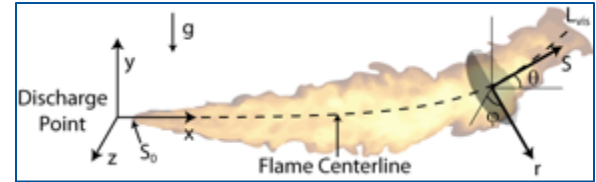
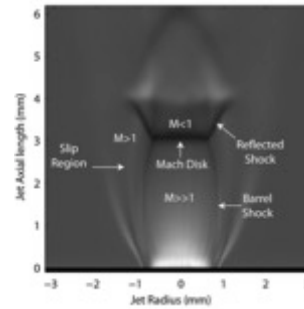
# Hydrogen Behavior studies enable predictive capabilities

Radiative properties of H<sub>2</sub> flames quantified



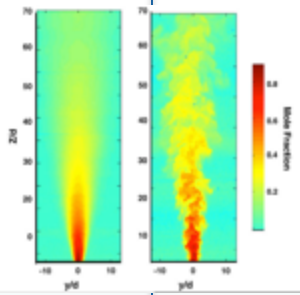
Barrier walls for risk reduction

Ignition of under-expanded H<sub>2</sub> jets



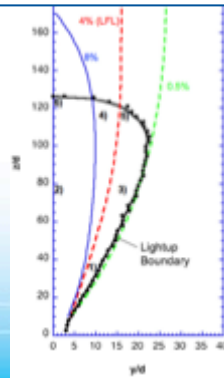
Buoyant jet flame model with multi-source radiation

2005      2007      2009      2011      2013      2015      2017

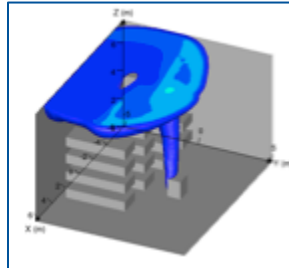


Advanced laser diagnostics applied to turbulent H<sub>2</sub> combustion

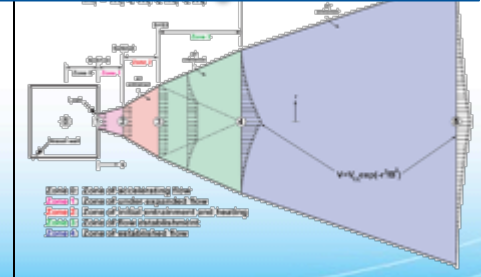
Ignition limits of turbulent H<sub>2</sub> flows



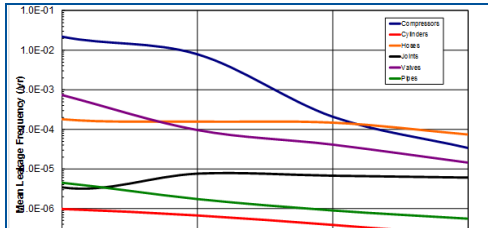
Experiment and simulation of indoor H<sub>2</sub> releases



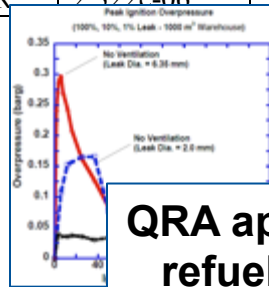
Laboratory-scale characterization of LH<sub>2</sub> plumes and jets



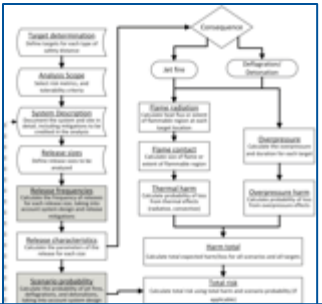
# Quantitative Risk Assessment is enabling infrastructure deployment



PLL	5.084e-04
FAR	0.1161
AIR	2.322e-06



**Performance-based system layout demonstrated**



**Established risk-informed processes for separation distances**

**QRA applied to indoor refueling to inform code revision**

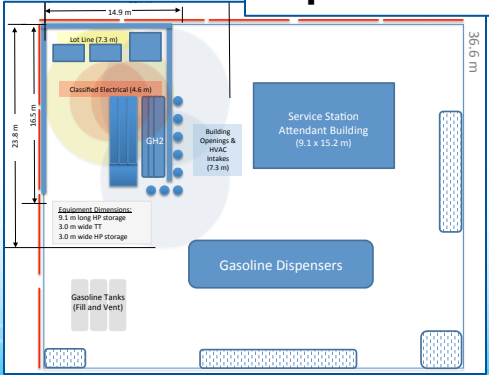
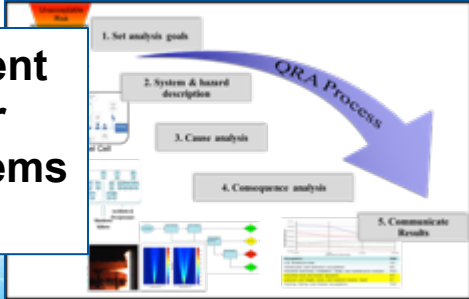
**ISO TC197 WG24 incorporating QRA and behavior modeling**

2005      2007      2009      2011      2013      2015      2017

**QRA-informed separation distances in NFPA 2**

**20% station penetration potential due to QRA**

**Risk assessment proposed for hydrogen systems at ICHS**

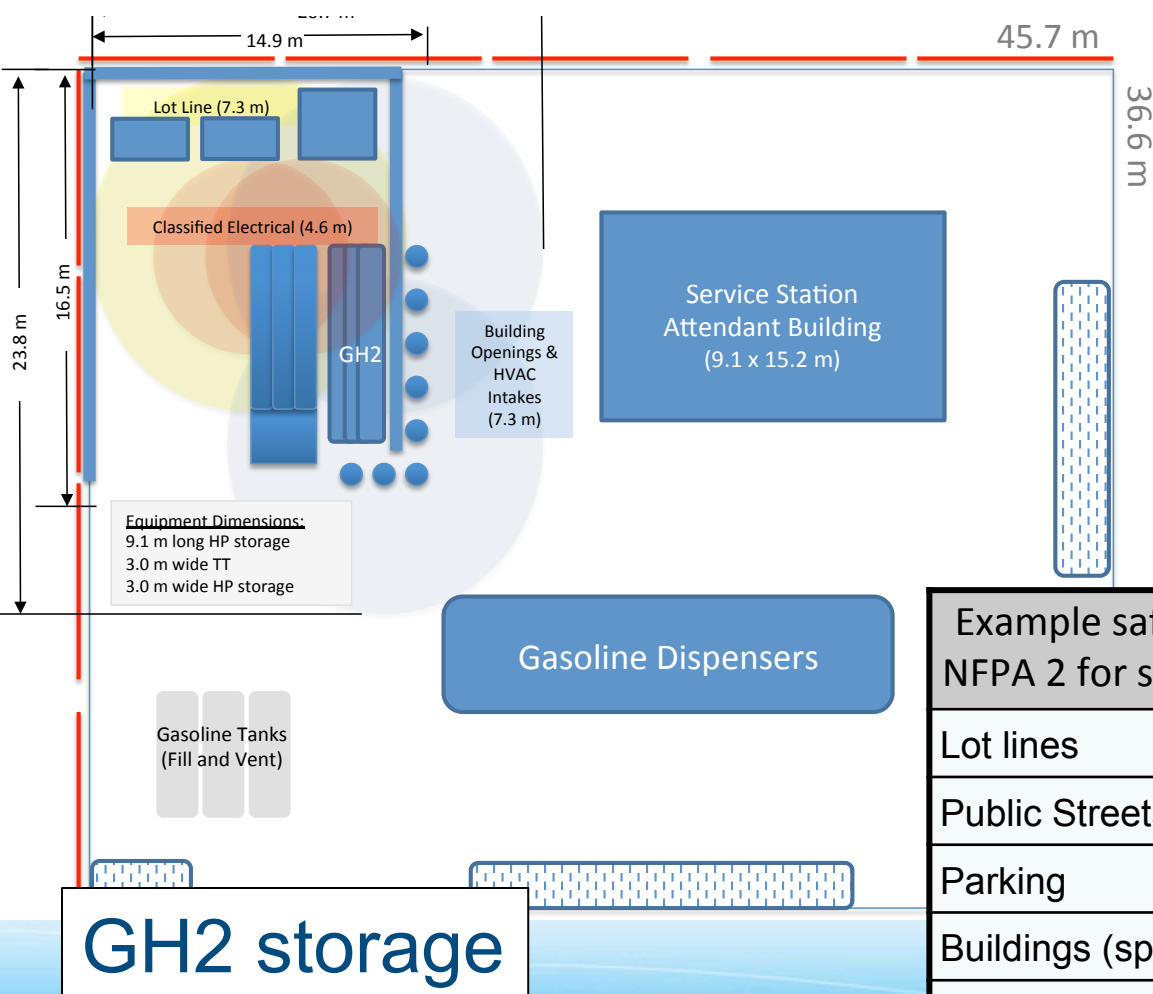


**HYRAM**  
HYDROGEN RISK ASSESSMENT MODELS

Scenario Ranking	Cut Sets	Importance Measure
Scenario	End State Type	Avg. Events/Year PLL Coroll.
10000	Explosion	0.0000 0
1000	Explosion	0.0000 0

**Public release of HyRAM R&D tool**

# Fire protection code reduced safety distances based on risk-informed, science-based methodology



**Outcome: initial safety distances precluded GH2 at existing fueling stations, science-based distances enable the acceptance of GHS at up to 20% of sites**

Harris et al. SAND2014-3416

Example safety distances (m)	GH2	LH2
NFPA 2 for specific boundaries		
Lot lines	7.3	10.1
Public Streets, Alleys	7.3	10.1
Parking	4.0	22.9
Buildings (sprinkled, fire rated)	3.0	1.5
Building Openings or air intakes	7.3	22.9



# Future challenge: Safety distances for liquid H<sub>2</sub> storage are too large for commercial fueling stations in the US

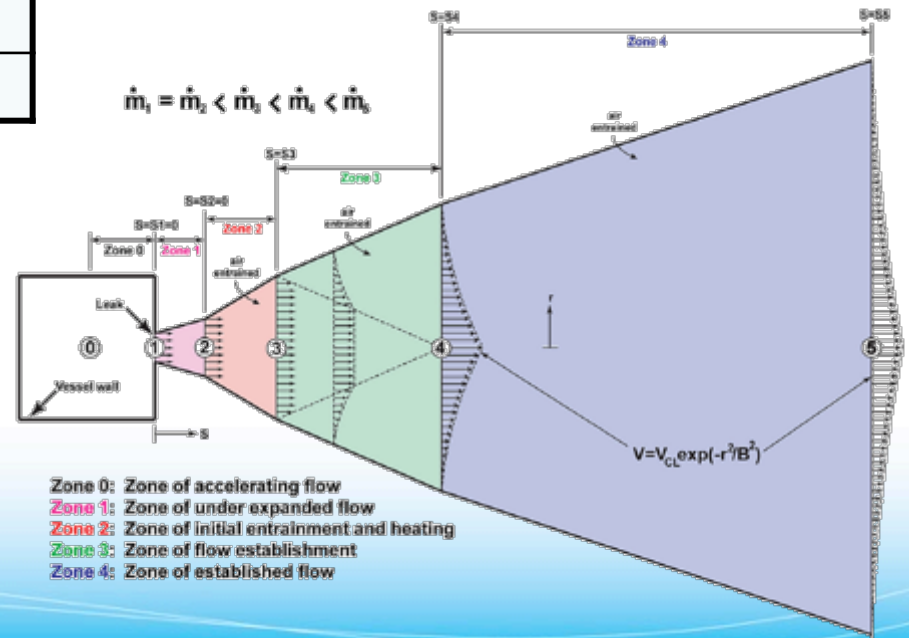
Example safety distances (m) NFPA 2 for specific boundaries	GH <sub>2</sub>	LH <sub>2</sub>
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Building Openings or air intakes	7.3	22.9

*Goal: use science-based approach to inform safety distances for LH<sub>2</sub>*

- NFPA activity

Harris et al. SAND2014-3416

**Validated models of LH<sub>2</sub> releases integrated into the QRA framework will inform quantification of risk and aid the definition of safety distances**



# Leadership in materials and components for hydrogen service

## Goal

Develop and characterize high-performance, hydrogen containment materials to lower capital cost of hydrogen infrastructure, systems and components



## Demonstrated Impact

- Enabled worldwide deployment of hydrogen and fuel cell systems by developing science-based standards



**SANDIA'S HYDROGEN PROGRAM**

Technical Reference for Hydrogen Compatibility of Materials

A technical guide is a necessary resource to develop codes and standards for hydrogen service and to facilitate the design, construction, and operation of hydrogen systems. This document provides a comprehensive overview of the state-of-the-art in hydrogen compatibility research, including the design, testing, and operation of hydrogen systems. The document is intended for use by researchers, engineers, and operators of hydrogen systems.

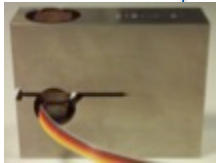
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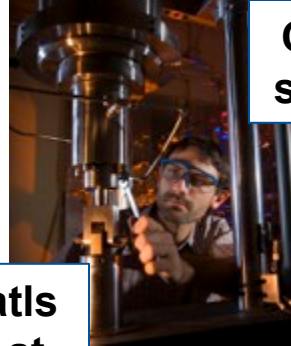
- Technology roadmaps
- Databases
- Leveraged research

# Evaluation of *Materials Compatibility* enables innovative technologies

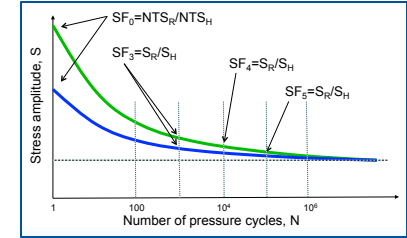
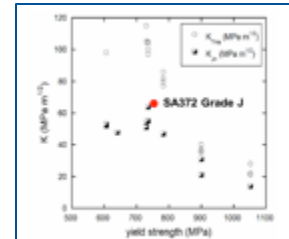
**ASME article KD-10  
input on test  
methodology**



**Platform for mats  
testing in GH2 at  
high pressure**



**Critical assessment of  
statically loaded cracks**



**CSA CHMC1  
test methods and  
mats qualification**

**2005                      2007                      2009                      2011                      2013                      2015                      2017**

**First qualification data  
for high-pressure  
ASME vessels**

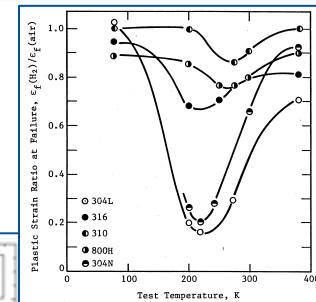
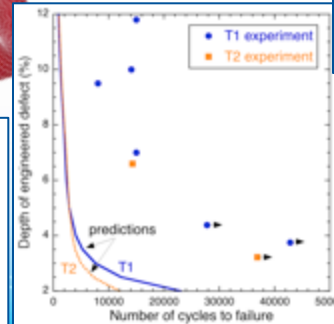
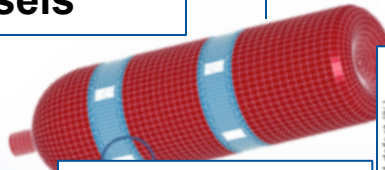
**SANDIA REPORT  
SAND2008-1163  
Unlimited Release  
Prepared March 2008**

**Technical Reference on Hydrogen  
Compatibility of Materials**

C. San Marchi  
B.P. Somerday

**Technical Reference  
established**

**Full-scale  
tank testing  
CSA HPIT1  
SAE J2579**



**Platform for high-  
pressure GH2 over  
temperature range  
(-40°C to +85°C)**

# Full-scale testing of pressure vessels enabled deployment of safe, low-cost fuel cell forklift fuel systems



plug power

NUVERA  
FUEL CELLS

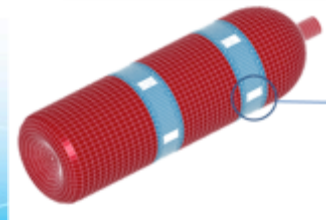
NORRIS  
CYLINDER

We quantified uncertainties in the cycle life of hydrogen storage tanks for the lift-truck application.

- Enhanced safety and market growth enabled through standards development



example of embrittlement failure from the 1970's



- Today, there are >5000 clean and efficient fuel cell forklifts in service (and growing!)



# Enabling the development and harmonization of hydrogen fuel quality standards

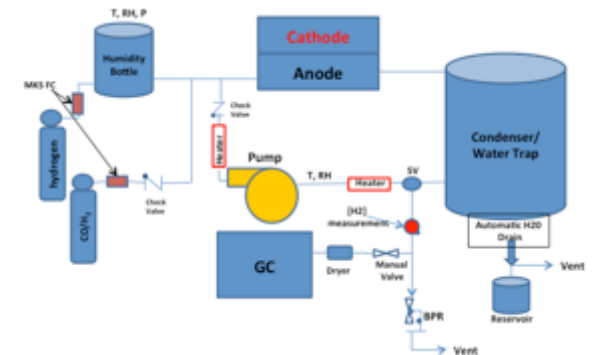
## Goal

Characterize effects of hydrogen fuel impurities on fuel cell performance, with the goal of harmonizing and standardizing fuel quality requirements to meet fuel cell performance targets



Partners:

- VTT-Finland
- JRC



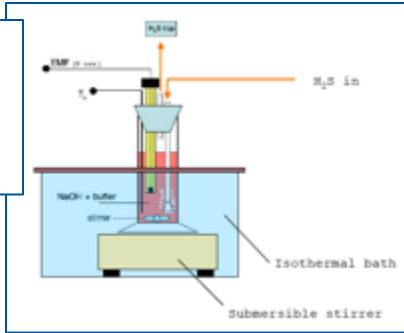
## Demonstrated Impact

- Enabled standardization of fuel quality requirements for fuel cell vehicles through quantitative assessment of PEMFC performance

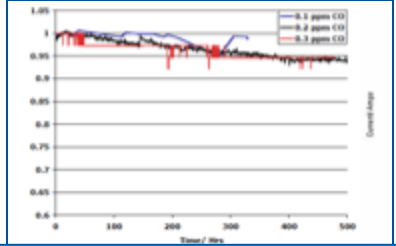
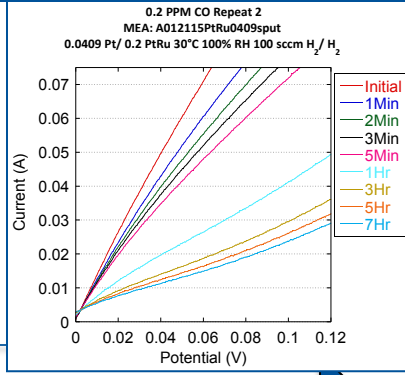


# Hydrogen fuel quality assessment enables vehicle deployment

Analytical method for H<sub>2</sub>S determination



In-line Fuel Quality Analyzer (proof of concept)

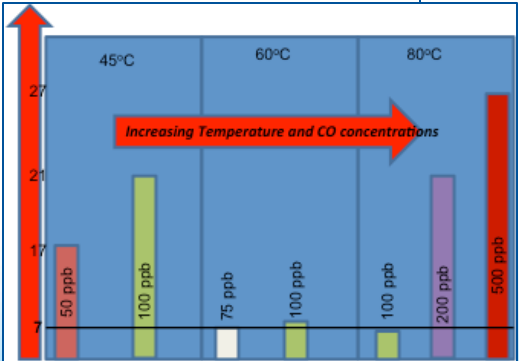
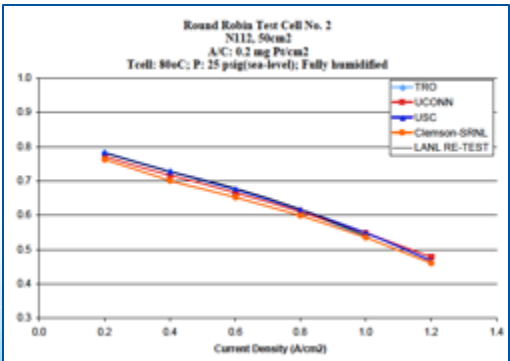


Data on H<sub>2</sub> fuel quality effects on PEMFC provided to set initial SAE J2719 standards

Chair ASTM sub-committee D03.14

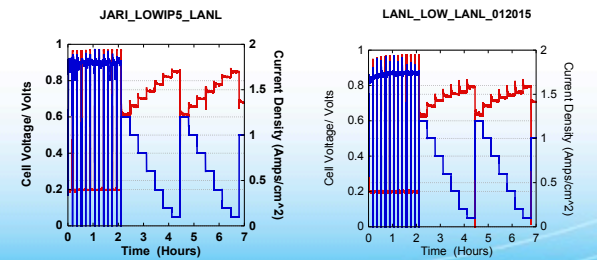


Round Robin testing



Effect of low Pt loading

Collaboration with JARI, and CEA to establish common protocols/test articles

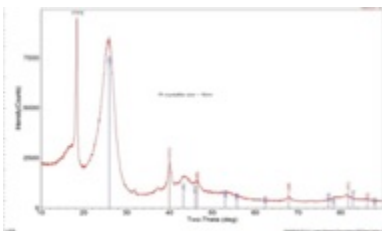


# Hydrogen contamination detector concept provides potential pathway for real-time monitoring of fuel quality

## Concept:

Real-time monitoring enabled by

- Sputtered Electrodes
- Low surface area
- Low loading



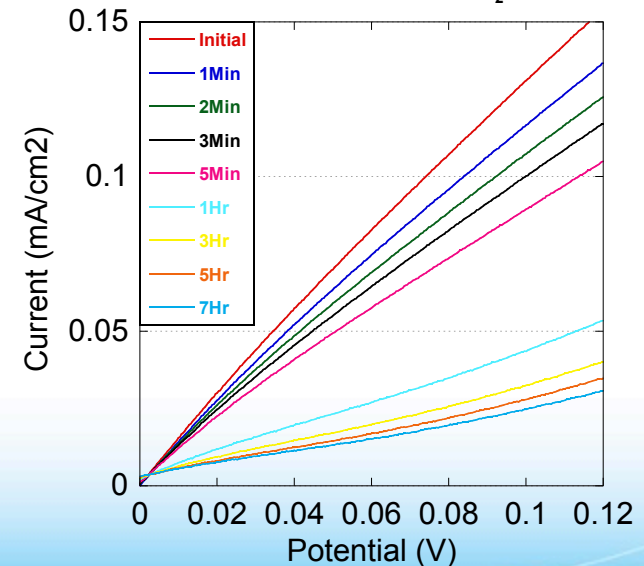
## Results:

High sensitivity of low loaded sputtered electrode

- Operated in H<sub>2</sub> pump mode at RT and 100%RH
- Responds to SAE J2719 levels of CO and H<sub>2</sub>S in < 1 minute
- Development of analyzer based on proof of concept is underway (Humidification, packaging, electronics)

0.2 PPM CO & 4 ppb H<sub>2</sub>S MEA:

Working Electrode: 0.0409 mg Pt/cm<sup>2</sup>  
100% RH; 100 sccm H<sub>2</sub>



## Summary

- Hydrogen behavior models enable safety analysis
  - Validated, defensible, referenceable models
- QRA framework enables science basis for revision of code requirements
  - Consistent, logical framework for quantifying risk
- Understanding of materials performance enables deployment of innovative technologies
  - Accommodate hydrogen effects by quantification of materials behavior in relevant hydrogen environments
- Harmonized test methods on the performance of PEMFCs enables revision of fuel quality standards