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

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Sandia National Laboratories

SAND2015-PE

Outline

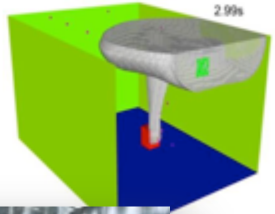
- **Hydrogen Behavior**
  – Bob Schefer, Bill Houf, Bill Winters, Greg Evans, Mark Grothe, Isaac Ekoto, Adam Ruggles, Ethan Hecht
- **Quantitative Risk Assessment**
  – Jeff LaChance, Katrina Groth, Chris LaFleur, Alice Muna
- **Hydrogen Compatibility of Materials**
  – Brian Somerday, Chris San Marchi, 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

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

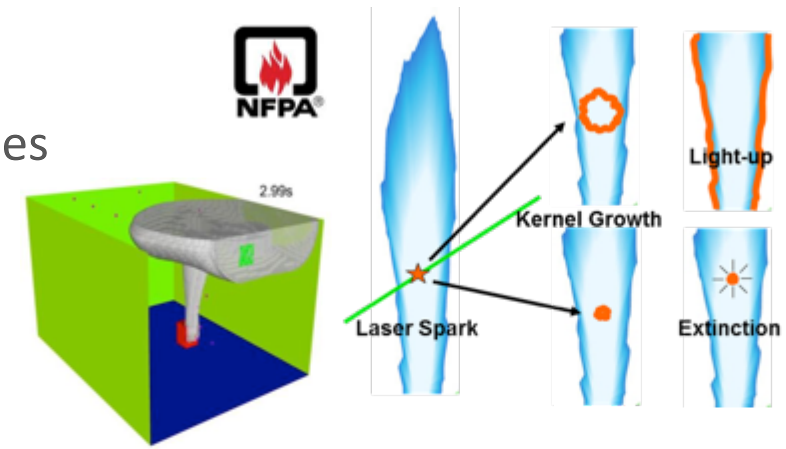
Science-based regulations, codes and standards ensure technology requirements are consistent, logical and defensible



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

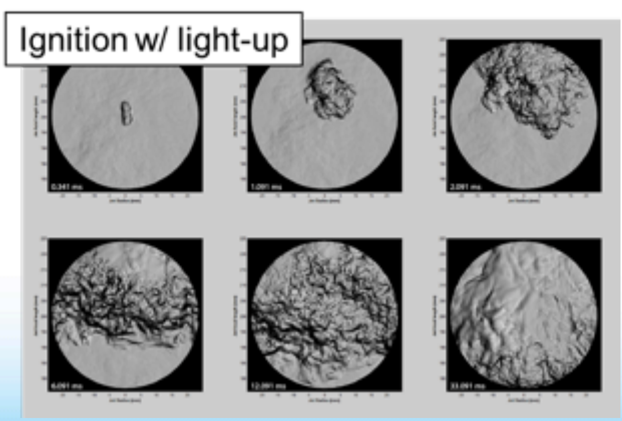
Goal

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



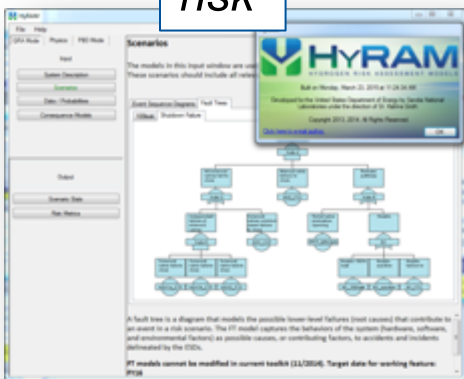
Demonstrated Impact

- 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

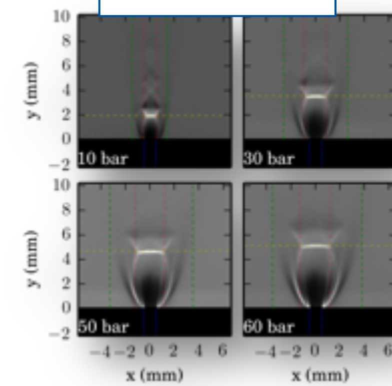
for enabling consistent, logical and defensible QRA

application

Apply quantitative risk assessment techniques

in real hydrogen infrastructure and emerging technology

behavior



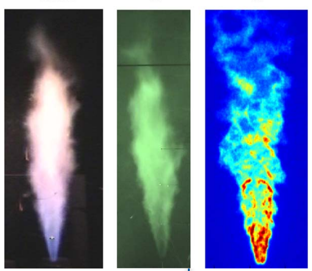
Develop and validate scientific models

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

HYDROGEN RISK ASSESSMENT MODELS

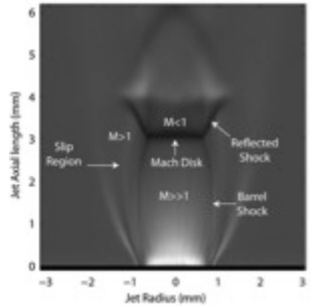
Hydrogen Behavior studies enable predictive capabilities

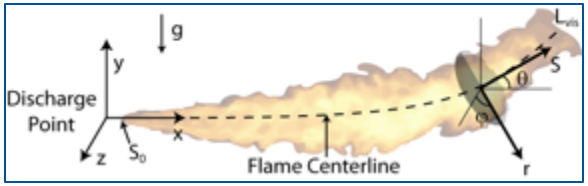
Radiative properties of H2 flames quantified



Barrier walls for risk reduction

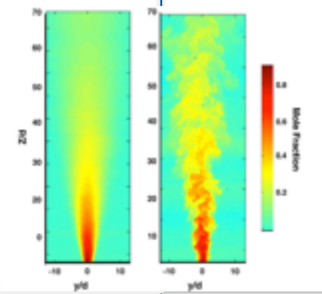
Ignition of under-expanded H2 jets





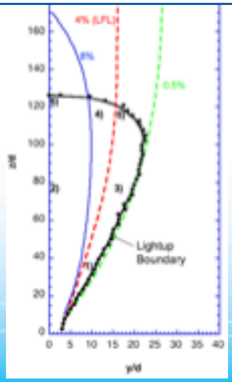
Buoyant jet flame model with multi-source radiation

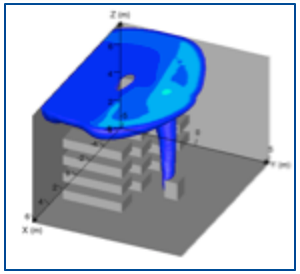
2005 2007 2009 2011 2013 2015 2017



Advanced laser diagnostics applied to turbulent H2 combustion

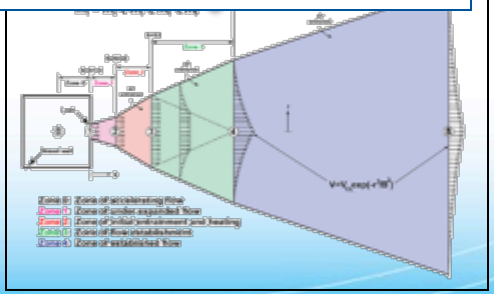
Ignition limits of turbulent H2 flows



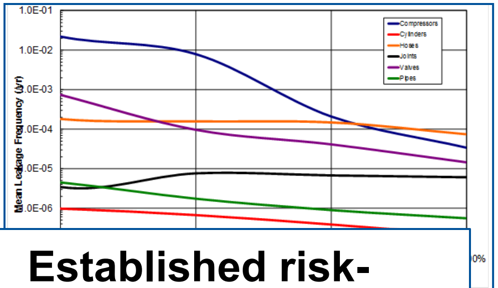


Experiment and simulation of indoor H2 releases

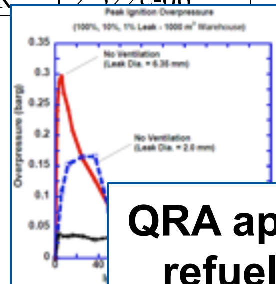
Laboratory-scale characterization of LH2 plumes and jets

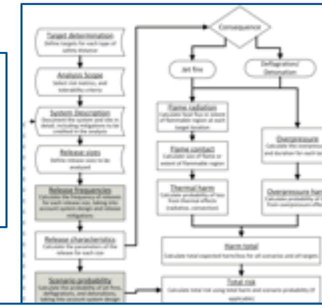


Quantitative Risk Assessment is enabling infrastructure deployment



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





Risk assessment proposed for hydrogen systems at ICHS (2005)

Established risk-informed processes for separation distances (2009)

QRA-informed separation distances in NFPA 2 (2011)

QRA applied to indoor refueling to inform code revision (2012)

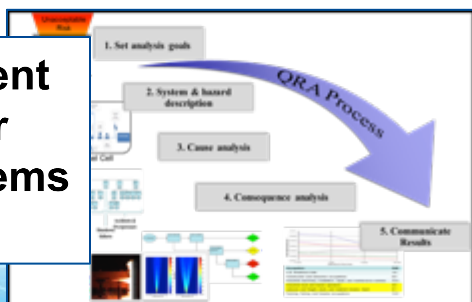
20% station penetration potential due to QRA (2014)

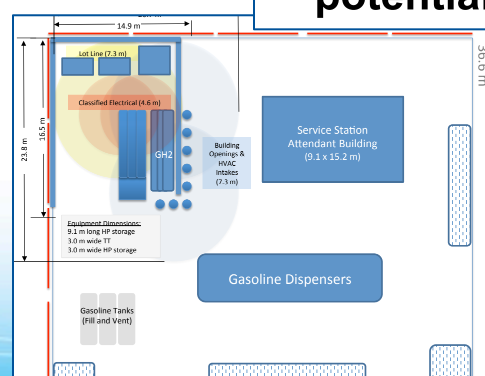
Performance-based system layout demonstrated (2015)

Public release of HyRAM R&D tool (2016)

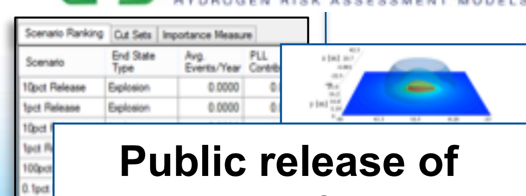
ISO TC197 WG24 incorporating QRA and behavior modeling (2017)

2005 | 2007 | 2009 | 2011 | 2013 | 2015 | 2017

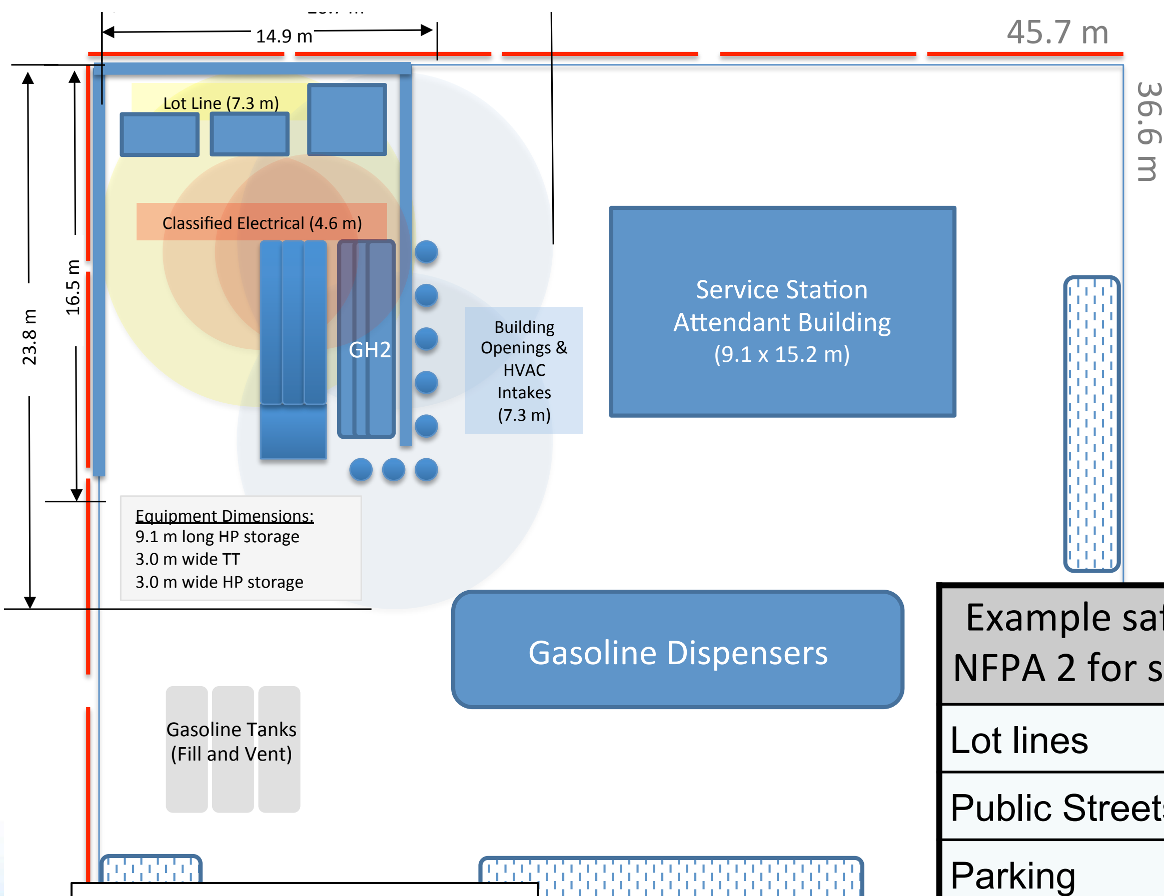




HyRAM HYDROGEN RISK ASSESSMENT MODELS



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



GH2 storage

***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) NFPA 2 for specific boundaries	GH2	LH2
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 H2 storage are too large for commercial fueling stations in the US

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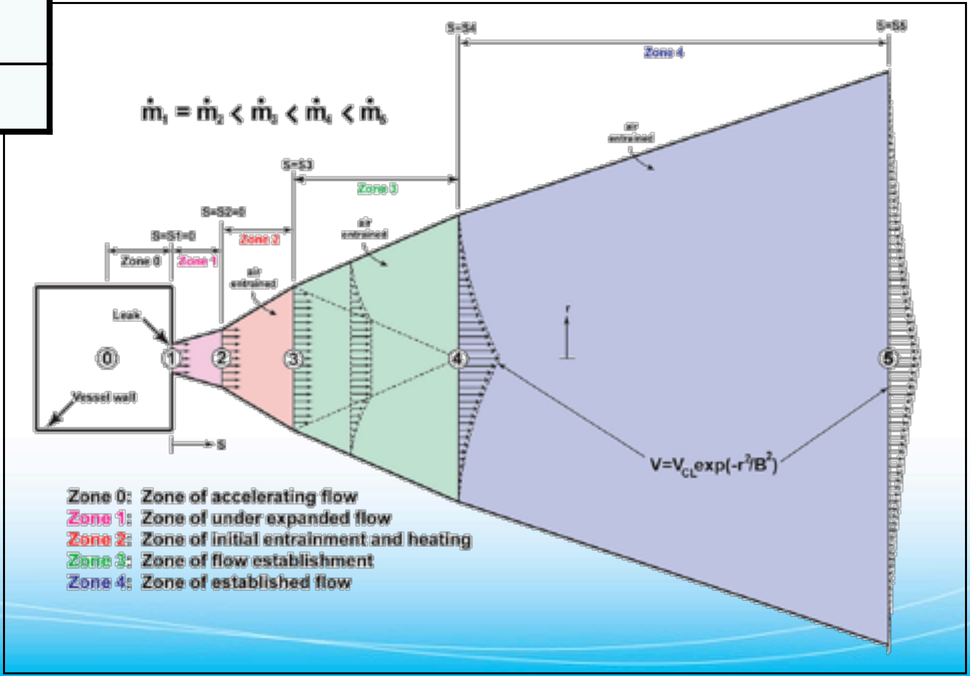
Harris et al. SAND2014-3416

***Goal*: use science-based approach to inform safety distances for LH2**
- **NFPA activity**

Validated models of LH2 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

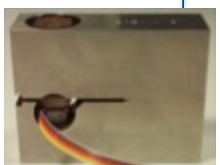
Demonstrated Impact

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

- Technology roadmaps
- Databases
- Leveraged research

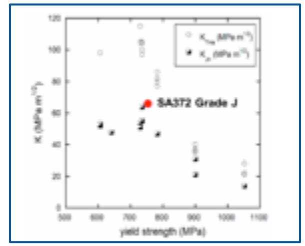
Evaluation of *Materials Compatibility* enables innovative technologies

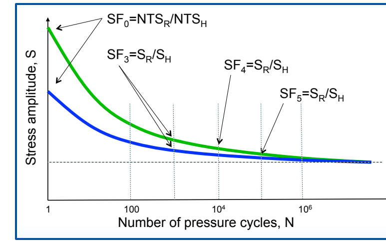
ASME article KD-10 input on test methodology



Platform for matls testing in GH2 at high pressure

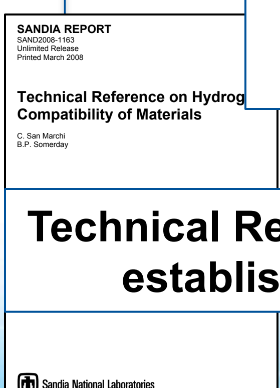
Critical assessment of statically loaded cracks





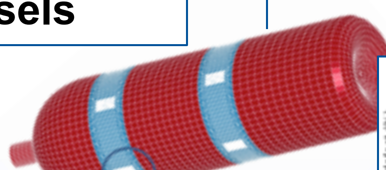
CSA CHMC1 test methods and matls qualification

2005 — 2007 — 2009 — 2011 — 2013 — 2015 — 2017

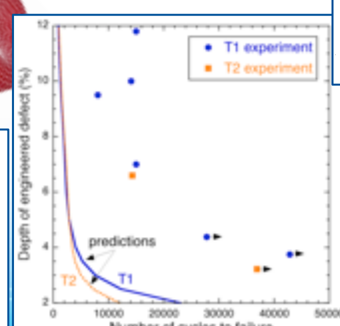


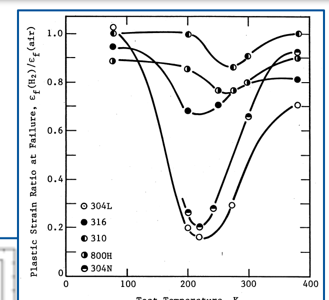
First qualification data for high-pressure ASME vessels

Technical Reference established



Full-scale tank testing CSA HPIT1 SAE J2579



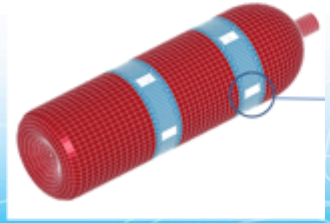


Platform for high-pressure GH2 over temperature range (-40˚C to +85˚C)

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

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!)

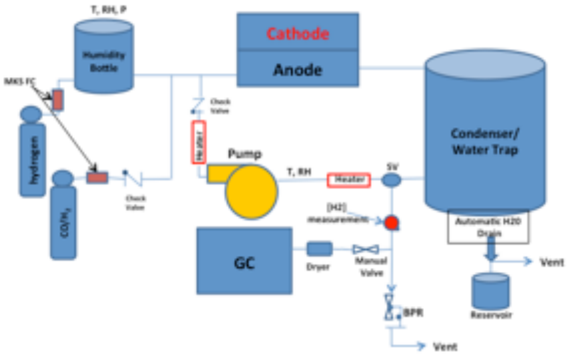
Enabling the development and harmonization of hydrogen fuel quality standards

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:

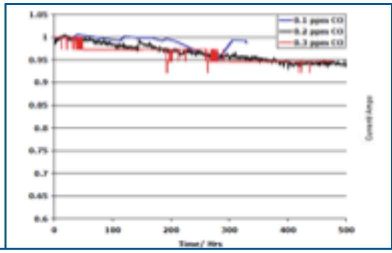
- VTT-Finland
- JRC



Demonstrated Impact

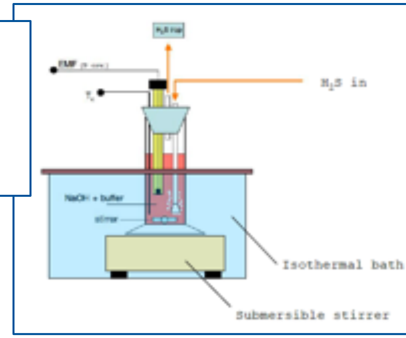
- Enabled standardization of fuel quality requirements for fuel cell vehicles through quantitative assessment of PEMFC performance

Hydrogen fuel quality assessment enables vehicle deployment



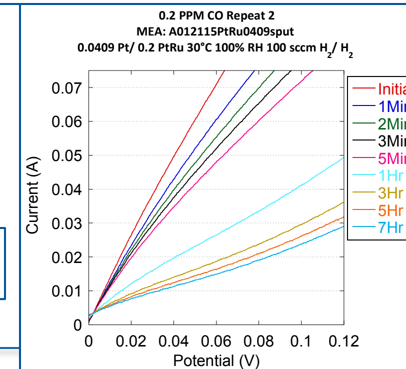
Data on H_2 fuel quality effects on PEMFC provided to set initial SAE J2719 standards

Analytical method for H_2S determination



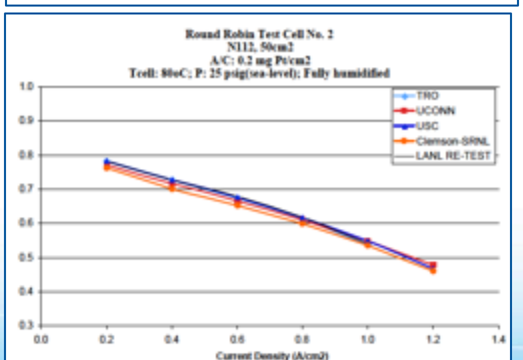
Chair ASTM sub-committee D03.14

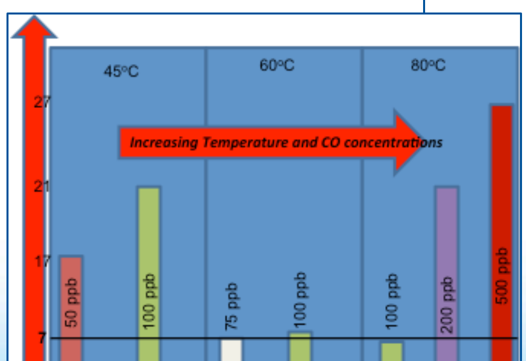
In-line Fuel Quality Analyzer (proof of concept)



2005 2007 2009 2011 2013 2015 2017

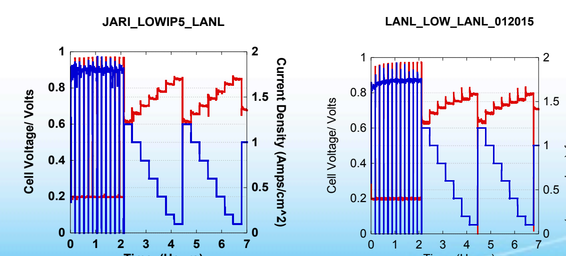
Round Robin testing





Effect of low Pt loading

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

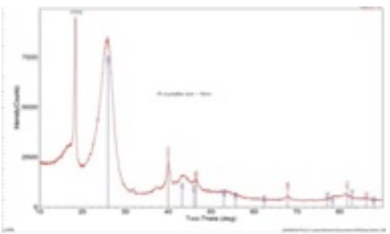


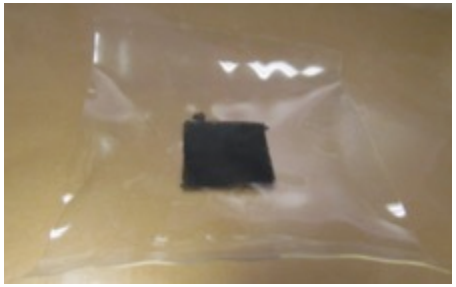
Hydrogen contamination detector concept provides potential pathway for real-time monitoring of fuel quality

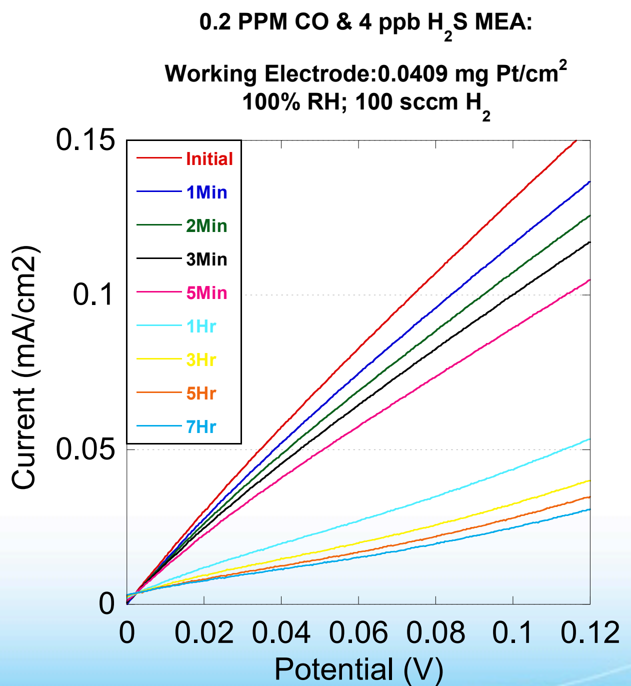
Concept:

Real-time monitoring enabled by

- **Sputtered Electrodes**
- **Low surface area**
- **Low loading**







Results:

High sensitivity of low loaded sputtered electrode

- **Operated in H_2 pump mode at RT and 100%RH**
- **Responds to SAE J2719 levels of CO and H_2S in < 1 minute**
- **Development of analyzer based on proof of concept is underway (Humidification, packaging, electronics)**

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