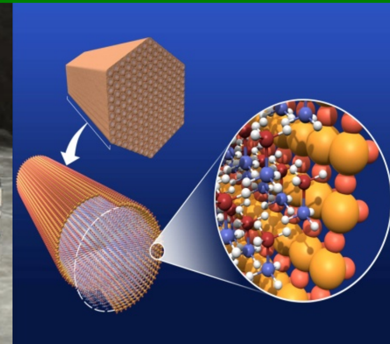
U.S. DEPARTMENT OF
ENERGY



Safety, Codes and Standards Program Area

- Plenary Presentation -

Will James

Fuel Cell Technologies Office

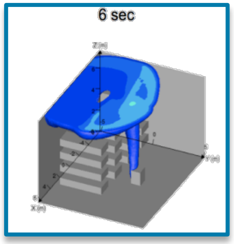
2014 Annual Merit Review and Peer Evaluation Meeting

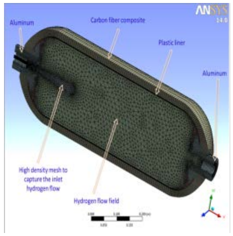
June 17, 2014

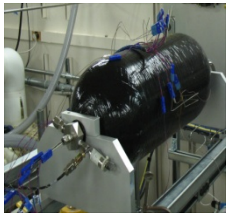
Goals and Program Objectives

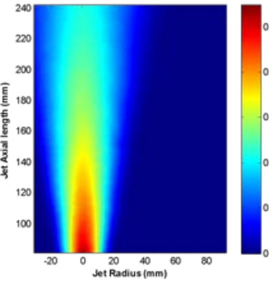
U.S. DEPARTMENT OF ENERGY

Enable the widespread commercialization of hydrogen and fuel cell technologies through the timely development of codes and standards









Objectives

- Support and facilitate development and promulgation of essential codes and standards by 2015 to enable widespread deployment and market entry of hydrogen and fuel cell technologies and completion of all essential domestic and international RCS by 2020.
- Conduct R&D to provide critical data and information needed to define requirements in developing codes and standards.
- Ensure that best safety practices underlie research, technology development, and market deployment activities supported through DOE-funded projects.
- Develop and enable widespread sharing of safety-related information resources and lessons learned with first responders, authorities having jurisdiction (AHJs), and other key stakeholders.

Strategy

Leveraging expertise from key domestic and international communities

C & S

Indentify R&D needs
- Facilitate stakeholder workshops, develop R&D roadmaps
- Analyze existing codes and standards, safety knowledge
- Participate actively in technical working groups

Perform High-Priority R&D
- Hydrogen behavior
- Quantitative Risk Assessments
- Compatible materials and components

Labs, academia, industry

Impact Codes and Standards
- Participate in technical committees to develop requirements
- Publish R&D results

Harmonize Internationally
- Regulations, Codes and Standards (RCS, GTR)
- International Standards (eg. ISO)
- International Agreements (IEA, IPHE)

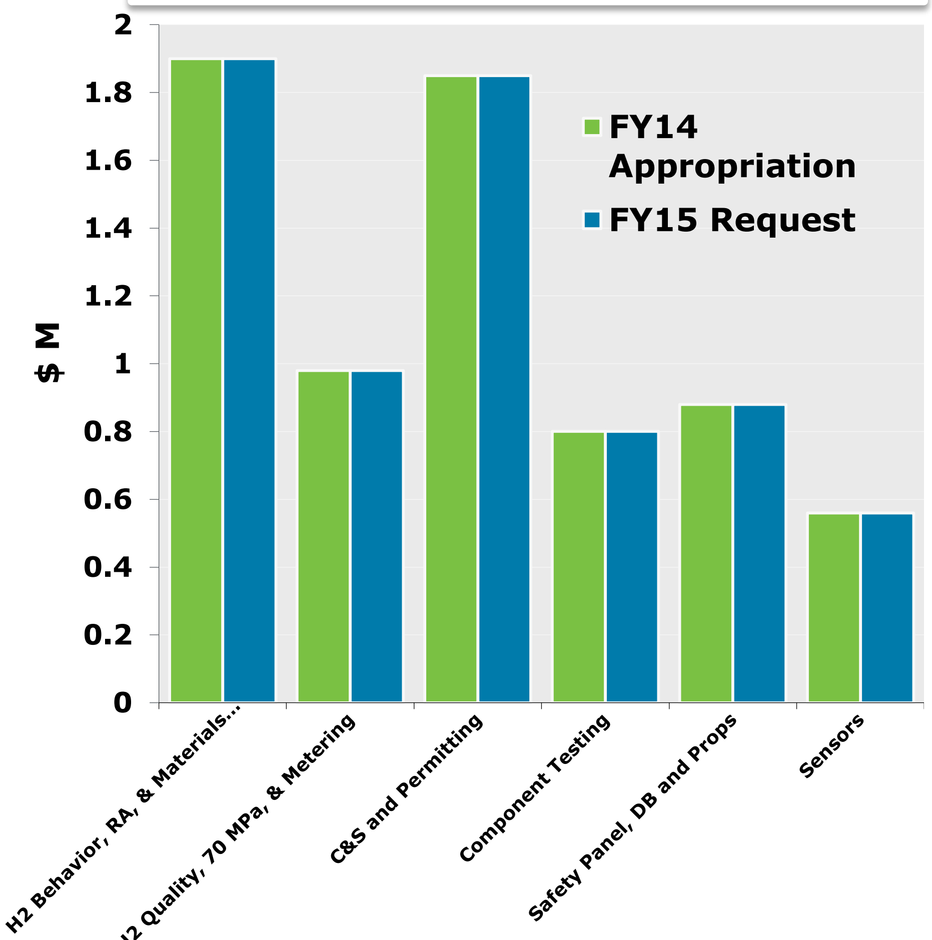
Safety

U.S. DEPARTMENT OF ENERGY

FY 2015 request allows for continued emphasis on critical RCS and safety

FY 2015 Request = $7M

FY 2014 Appropriation = $7M



Emphasis:

- Develop technical understanding and performance data to support RCS
- Facilitate hydrogen fueling station permitting for early market deployment
- Verify fuel quality and station fill performance
- Establish protocols to identify & mitigate risk
- Develop protocols for station qualification
- Disseminate hydrogen “best practices” and safety information

Accomplishments: Regulations, Codes, & Standards

U.S. DEPARTMENT OF ENERGY

Initial codes and standards pave way for implementation and deployment of hydrogen infrastructure and light duty vehicles

Infrastructure	
Primary Building and Fire Codes	Integration of NFPA2 into the IFC
Component Standards and Design Codes	CSA HGV 4.1 CSA HGV 4.2 CSA HGV 4.4 CSA HGV 4.5 CSA HGV 4.6 CSA CHMC1

*Note: ISO WG24 has started with an accelerated timeline of 24 months for IS.

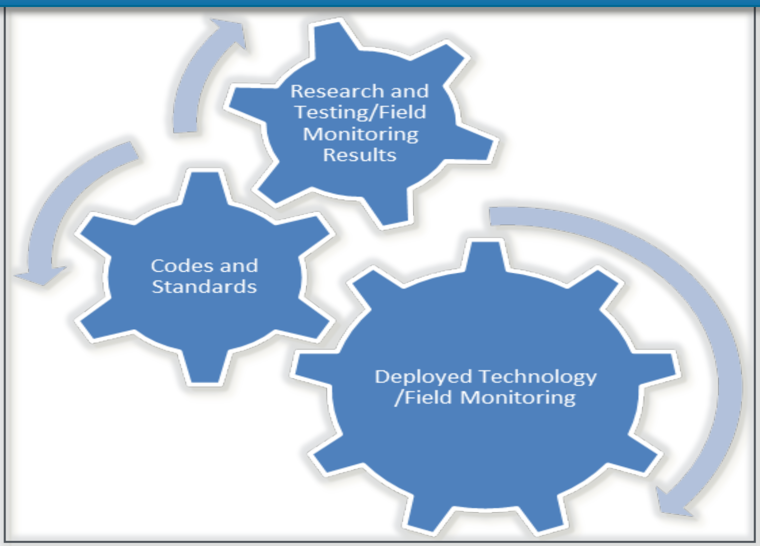
Vehicle	
Regulatory	Global Technical Regulation adopted by the UNECE Working Party 29
Component Standards and Design Codes	SAE J2579 SAE J2799 SAE J2601

*Note: Expected timeline for U.S. adoption of GTR is three years.

Accomplishments: C&S Infrastructure Deployment Guide and Tools

NREL is providing interface between standards development organizations and DOE supported component test programs

CCSI



- CCSI covers the need for further advancement of the foundational codes and standards
- Incorporate field data and user feedback in new or revised C&S
- Address safety concerns from early phase deployments

Component R&D

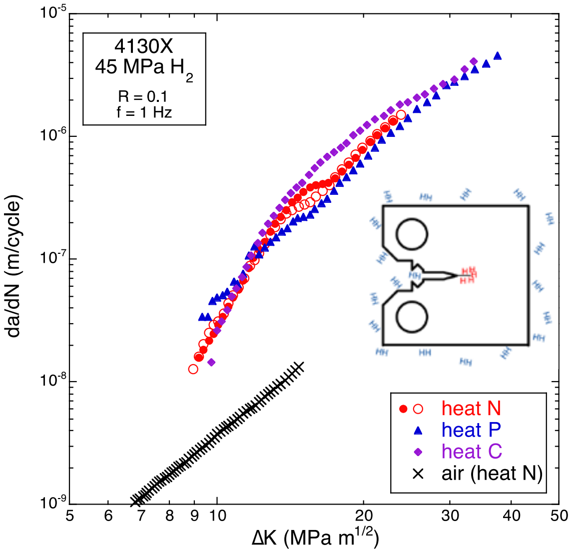
Published report on PRV applications in hydrogen environments and completed accelerated life testing of PRVs including: qualitative reliability testing and failure mode investigation

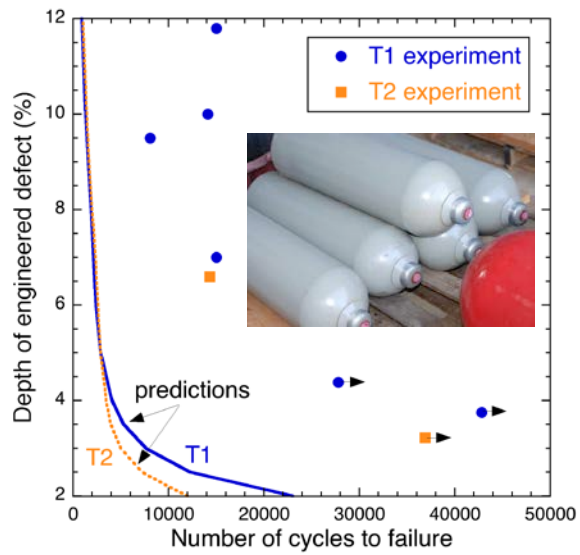
Accomplishments: Materials Compatibility

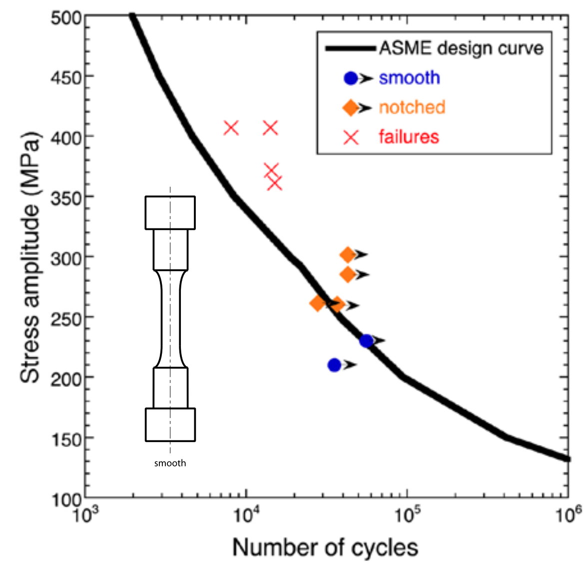
U.S. DEPARTMENT OF ENERGY

At SNL, integrated materials and component testing program establishes pathway to potential new materials

Fatigue crack growth method → Component tests → Stress-based fatigue method





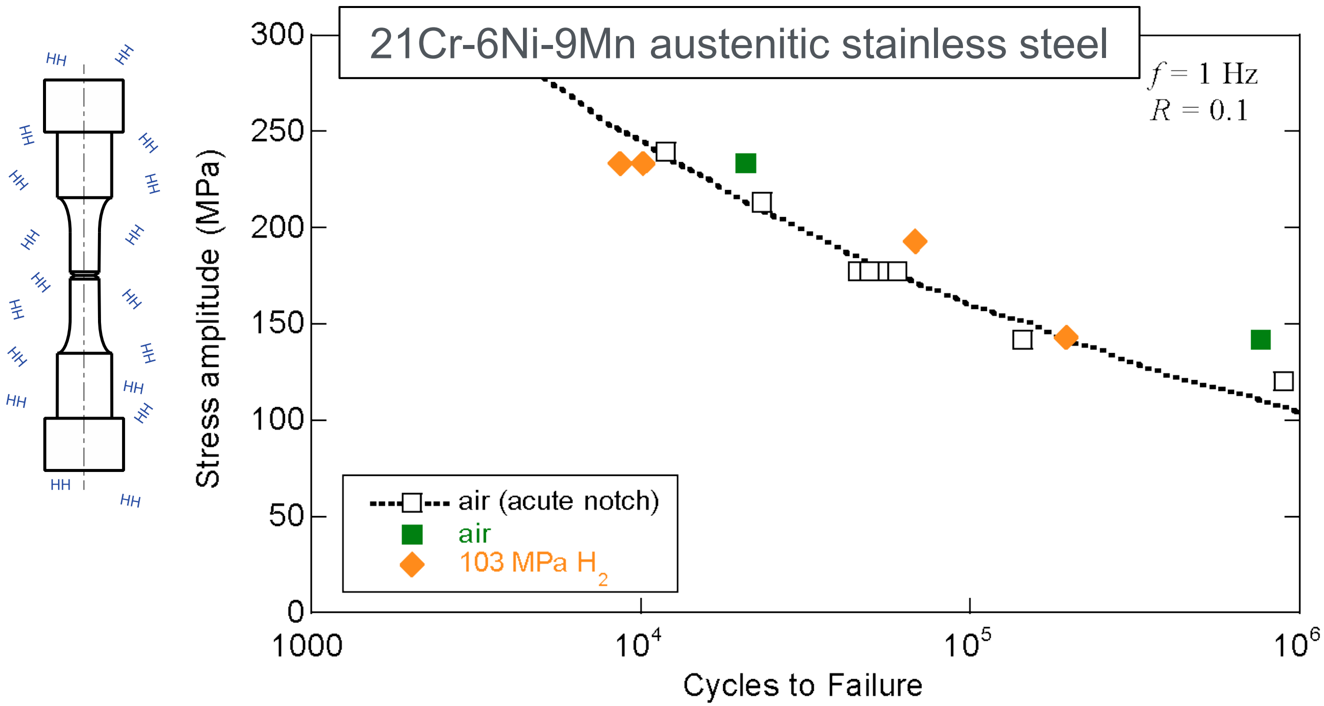


- Predictions using fatigue crack growth testing (ASME BPVC VIII.3 protocol KD-4) is very conservative, if cracks take time to initiate
- Stress-based fatigue method (ASME BPVC VIII.3 protocol KD-3) offers an alternative to fracture mechanics
- Available stress-based fatigue data (S-N curves) in gaseous hydrogen is very limited in the literature

Accomplishments: Materials Compatibility

U.S. DEPARTMENT OF ENERGY

Austenitic stainless steel provides life-time cost reductions



- Strength of annealed 21Cr-6Ni-9Mn is >2x strength of annealed type 316L
- Cost of 21Cr-6Ni-9Mn bar material is ~80% of type 316L bar

- Hydrogen reduces total fatigue life
- High fatigue stress can be achieved with cycles to failure greater than 10,000 cycles
- Broader evaluation of methodology requires testing under combination of low temperature and high pressure (FY2015)

Accomplishments: Fuel Quality Analyzer

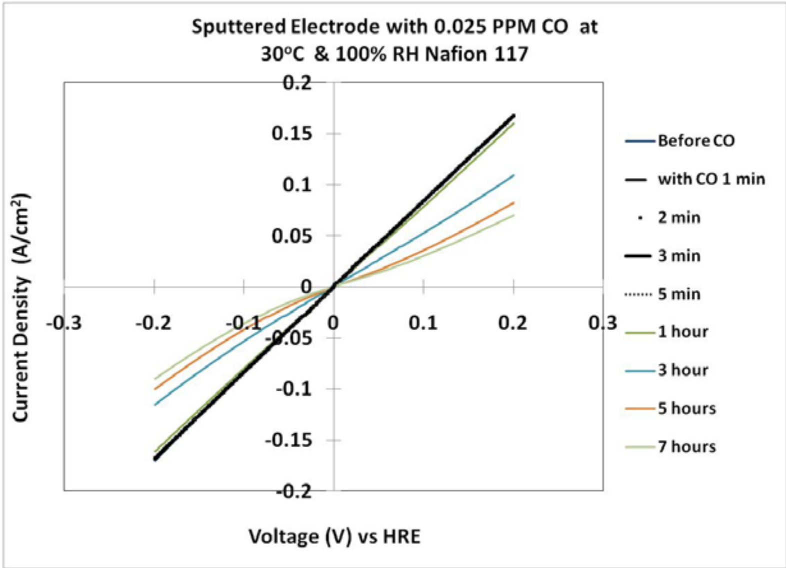
U.S. DEPARTMENT OF ENERGY

LANL is looking at proof of concept inline hydrogen analyzer to continuously monitor impurities and alert the user to any fuel quality issues

Concept: Use a fuel cell type device to measure impurities in the fuel stream. The device should be:

- Sensitive to the same impurities that would poison a fuel cell stack
  - Use same components (Nafion®, Pt and C) as the fuel cell stack
- Orders of magnitude more sensitive to impurities than the fuel cell stack
  - Use extremely low Pt loading and low surface areas
- Durable and low cost
  - Use small area cells, large Pt particle sizes (eliminate carbon), and thick electrolytes

- Demonstrated sensitivity to 25 ppb CO and 10 ppb H_2S in a H_2 pumping cell
- The decrease in current is proportional to the poisoning dosage
- Demonstrated that potential can be used to impart selectivity (CO vs H_2S) to the analyzer



Quantitative Risk Assessment

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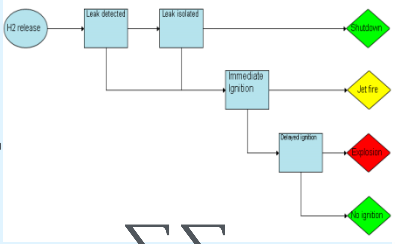
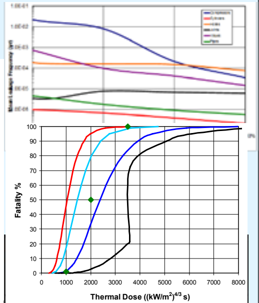
Developed, validated, and integrated models

QRA method, data & models (FY08-11)

- Hazards
- Accident sequences
- Release frequencies
- Ignition probabilities
- Harm/damage

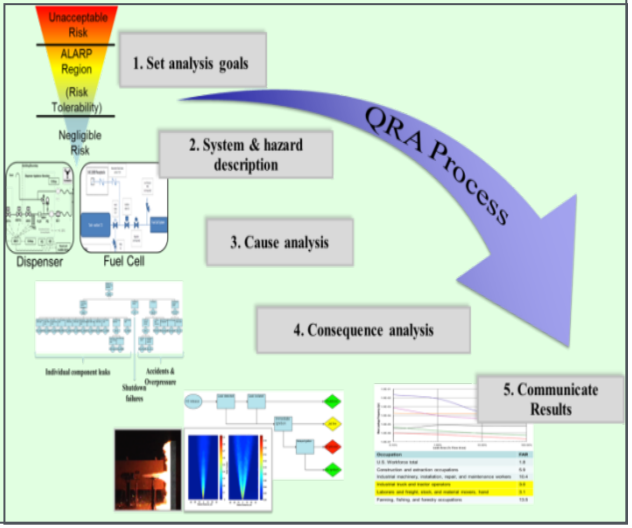




$$\text{Risk} \sim \sum_n \sum_j (f_{nj} \cdot c_{nj})$$

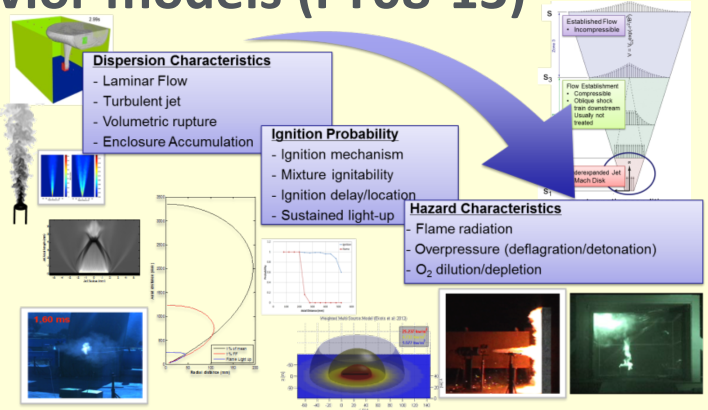
<0.125	0.008	0.004
0.125 – 6.25	0.053	0.027

Integrated algorithm & v0 toolkit (Matlab®) (FY12-13)



Physics-based behavior models (FY08-13)

- GH_2 release
- Ignition
- Reduced-order jet flame models
- Deflagration simulation



QRA-informed C&S (FY11-13)

- Indoor fueling (NFPA2 Ch. 10)
- Station separation distances (NFPA2 Ch.7)

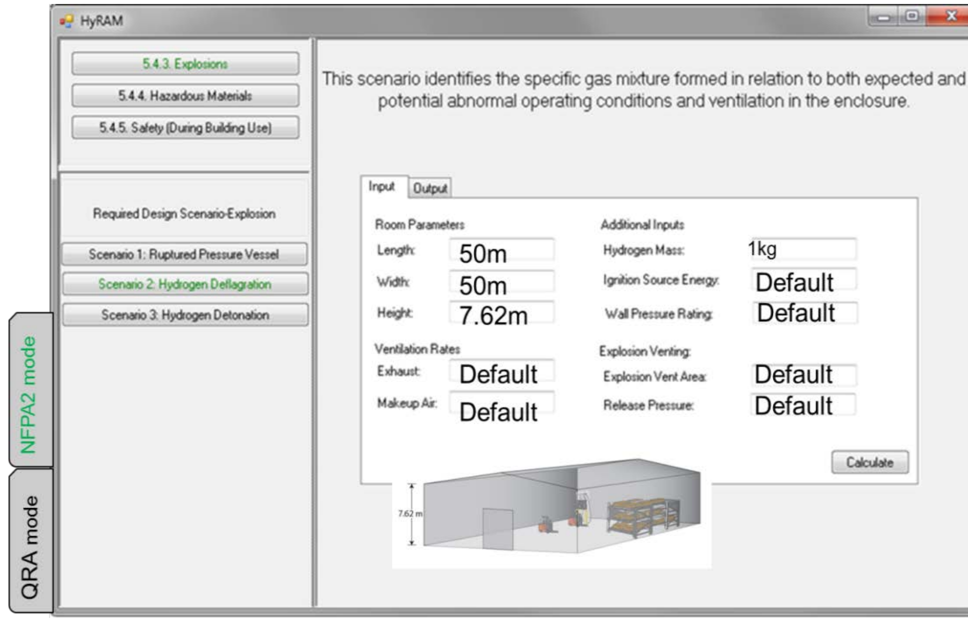
Gaps/Needs: 1) User-friendly toolkit to enable CDO-led QRAs, industry-led PBD siting option 2) Reduced-order deflagration models 3) downstream jet flame physics 4) Models for LH_2 releases

Accomplishments: Quantitative Risk Assessment

U.S. DEPARTMENT OF ENERGY

Developed toolkit to enable integrated probabilistic and deterministic modeling for end users

- Developed toolkit to enable integrated probabilistic and deterministic modeling
  - All relevant hazards (thermal, mechanical, tenability)
  - Probabilistic models & data
  - H_2 phenomena (gas release, ignition, heat flux, overpressure)
- Variable Users
  - High level, generic insights (e.g., for C&S developers, regulators)
  - Detailed, site-specific insights (e.g., for AHJs, station designers)
- Currently, two interfaces (views):
  - **"QRA mode"** and **"NFPA2 mode"**
  - Planned "standalone physics model" mode



- First-of-its-kind software tool for integrating H_2 consequence models w/ QRA models
- Includes behavior models & data developed through FY12
- Demonstration will take place Thursday, June 19th

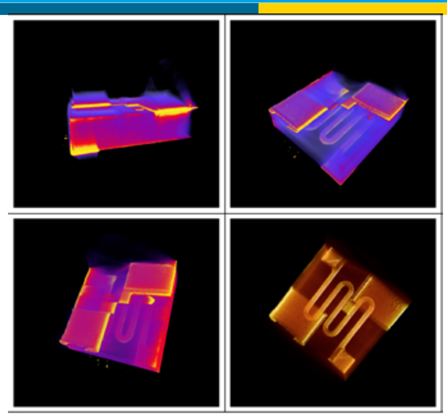
Accomplishments: Sensors

U.S. DEPARTMENT OF ENERGY

Develop and commercialize low-cost, durable, and reliable hydrogen safety sensor for stationary and infrastructure applications, extendable to vehicle protection

NREL

- Provide independent assessment of hydrogen sensor performance
- Collaborations with Government Agencies
  - US DOT-NHTSA: Ad Hoc Group--hydrogen vehicle sensors requirements (FMVSS, GTR)
  - Joint Research Center, Institute for Energy and Transport, (JRC-IET) European Commission
  - Federal Institute for Materials Research and Testing (BAM) Berlin



LANL & LLNL

- Sensor and signal / heater electronics integrated into a single unit with wireless communications
- Completed a 3rd round of testing at NREL
- Preparing for field validation testing

SBIR (Applied Nanotech)

- Tested the microresonant hydrogen sensor at different pressure, humidity, and temperature conditions and hydrogen concentrations
- A fully functional engineering sensor prototype was demonstrated and delivered to NREL for evaluation

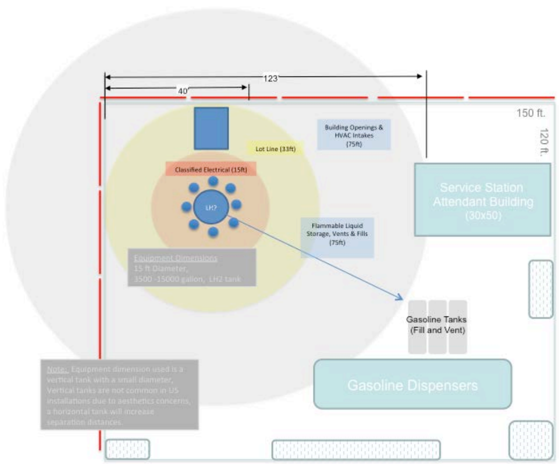
Accomplishments: Accelerate Deployment of HRS

U.S. DEPARTMENT OF ENERGY

Initiate performance-based design and liquid release tasks to impact the deployment hydrogen fueling stations

Performance-Based Design (PBD)

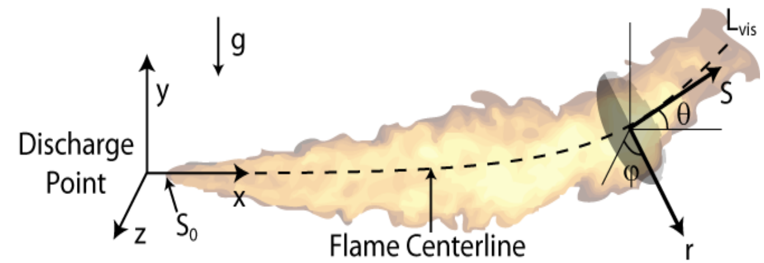
- Demonstrated the use of the QRA toolkit to develop and analyze a PBD
- A PBD Brief has been prepared for a representative refueling station



Demonstrating successful use of PBD option may significantly increase number of available sites - if industry can use PBD option in a cost-effective manner

Liquid Releases

- Current Separation distance are large and makes citing LH_2 stations difficult
- Leverage experience from gaseous hydrogen work
- Leverage industry through participation in NFPA 2/55

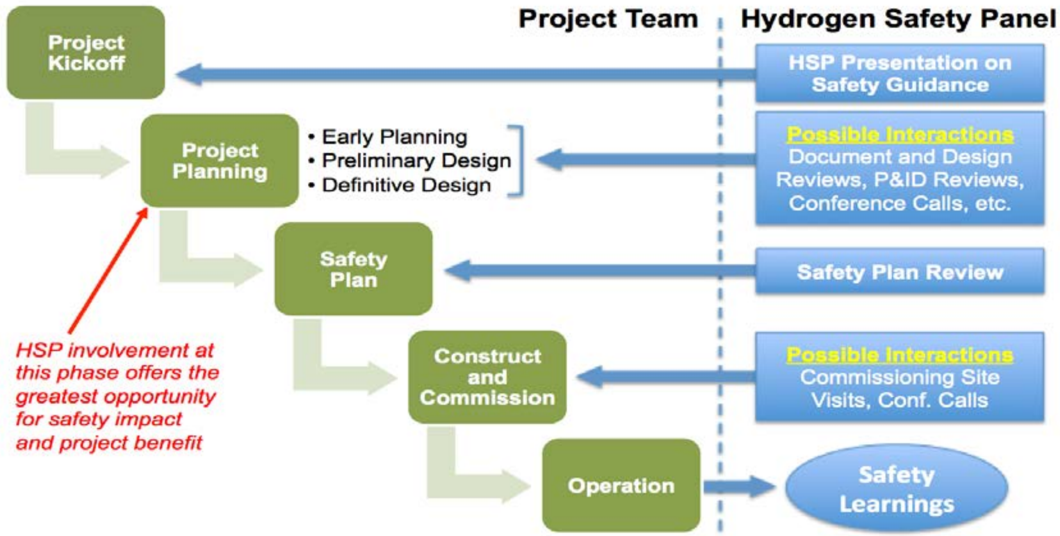


Develop work plan for liquid hydrogen releases and initiate initial experiments in FY2015

Hydrogen Safety Panel

U.S. DEPARTMENT OF ENERGY

Earlier involvement by the HSP, managed by PNNL, offers great opportunity to impact projects



Authored a May/June 2014 *NFPA Journal®* article focusing on hydrogen safety which highlights the Hydrogen Safety Panel and DOE's Hydrogen Emergency Response Training for First Responders circulated to (70,000 individuals in 100 countries)

Activity	Since the 2013 AMR	Total for the Project Duration
Project Reviews (including safety plans, site visits reviewed, follow-up interviews and design review activities)	12 (includes 3 early project reviews)	395
Panel Meetings	2 (Washington, DC and Golden, CO)	20
White Papers & Recommendations (e.g., *Safety of Hydrogen Systems Installed in Outdoor Enclosures*)	1	7
Publications and Presentations (both projects combined total)	5	39

SCS Training Totals and Impacts

U.S. DEPARTMENT OF ENERGY

First responder training at PNNL is important to enable commercialization of fuel cell and hydrogen technologies

Multiple instructors for classroom training

A "rescue" at Sunnyvale (CA) Department of Public Safety

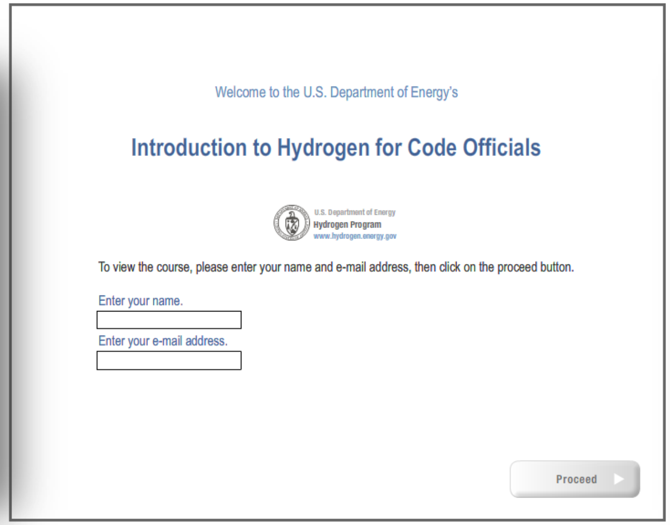
http://hydrogen.pnl.gov/FirstResponders/

- **TOTAL First Responders Trained = 28,000+**
- **Emphasis within H2USA and the Market Support and Acceleration Working Group**
- **Works closely with the CaFCP to conduct training across California**

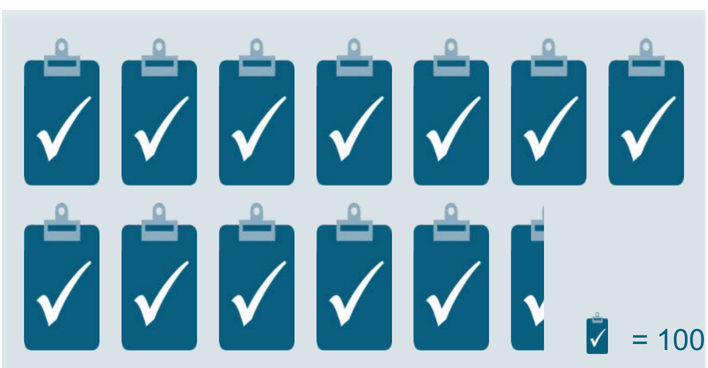
SCS Training Totals and Impacts

U.S. DEPARTMENT OF ENERGY

Code official training at NREL is an important outreach tool to enable commercialization of fuel cell and hydrogen technologies



http://www.hydrogen.energy.gov/training/code_official_training/



- **TOTAL CODE OFFICIALS TRAINED = 1,200+**
- **Most recent training occurred on May 19th (Huntington Beach) and May 27th (Culver City) through the CEC and CaFCP**
- **Emphasis within H2USA and the Market Support and Acceleration Working Group**

Education and Training

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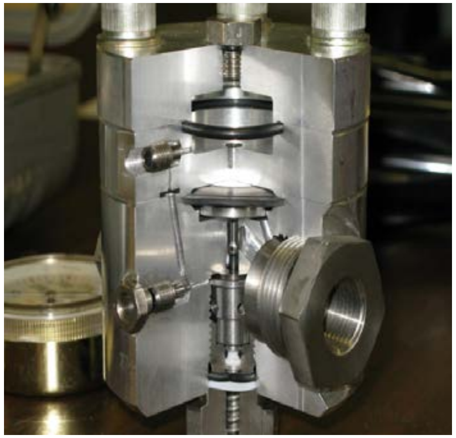
Hydrogen safety training is key to avoiding and responding to incidents

Researchers (LLNL)

- *Web-based class* (4 hours) developed for laboratory researchers handling hydrogen (completed)
- *300+ registered*



Hands-on safety class (3 days) developed for technical personnel in charge of designing, assembling, and testing H_2 systems (completed several sessions of materials and developed many training aids)

First Responders (PNNL)

First Responder Template

- Intro
- H_2 and Fuel Cell Basics
- H_2-Fueled Vehicles (light duty and transit)
- Stationary Facilities
- Managing H_2-Related Emergencies
- Practical Exercise

National Hydrogen Response Education Program- Arrange training materials into a multi-level training program appropriate for users with a variety of training perspectives, interests and needs.

Infrastructure and Safety Tool Development

U.S. DEPARTMENT OF ENERGY

The widespread availability and communication of safety-related information are crucial to ensure the safe operation and development of future hydrogen and fuel cell technology systems

Safety (PNNL)

Strategic meeting held April 1 and 2nd with 20 stakeholders, successfully evaluated resource tools for their impact/ease of development. The results of the session revealed areas where the various user groups could benefit from a different approach to providing safety knowledge resources, including:

- **Hydrogen safety web portal** – a "one-stop shop" for credible and reliable safety information
- **Codes and standards wizard** – utilizing questions to direct users to the applicable requirements and resource documents
- **Videos, Wiki's and networking tools** to help educate and connect users

Report will inform future funding decisions regarding tool development.

Infrastructure (NREL)

- California Template for Permitting Hydrogen Fueling Stations published in 2012
- Development of training videos for Project Planning and Plan Reviews (Part 1); Project Inspections (Part 2) underway
- Code Official In-Person trainings May19th and 27th (Los Angeles)
- Active participation on codes and standards technical committees including identifying research needs and bringing information to committees

				Affected			
ID #	Functionality	Impact	Ease	AHJ	FR/SR	OM	
GI-4	General safety information on properties of hydrogen and its behavior, including a Wiki and videos and diagrams showing important safety features, pressure safety, flame arrestors, vent systems and relief devices	5	4	✓	✓	✓	
GI-1	Hydrogen safety portal as a credible and reliable and one stop shop for safety information	5	3	✓	✓	✓	
CS-1	A clear overview of applicable codes and standards using	5	4	✓		✓	
DR-3	Modeling tools to predict consequences of cryogenic releases, pv failure, cryogenic to gas releases, gaseous releases, BLEVEs, etc., to support station layout and risk informed changes to regulation, codes and standards	5	3	✓			✓
DR-5	Enable the performance of risk assessments and provide options for risk mitigation, support performance-based analysis, include checklist functionality for basic risk, component databases, calculators and cost-benefit features	5	3	✓			✓
GI-3	Vehicle and equipment information covering general information, safety features, safe usage parameters,	4	3	✓	✓	✓	

New Ways to Share Safety Knowledge

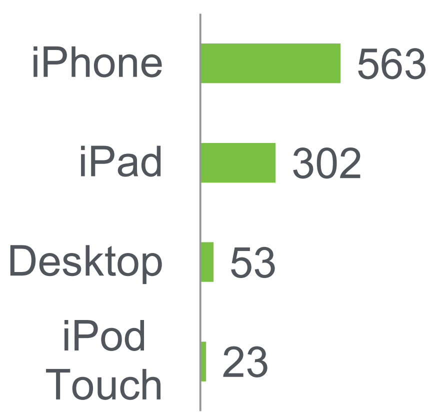
U.S. DEPARTMENT OF ENERGY

First mobile app developed for the Fuel Cell Technologies Office

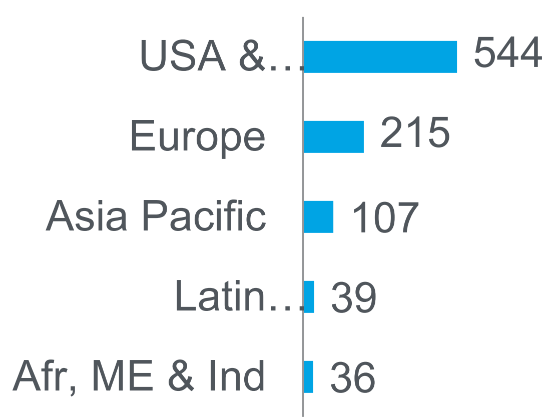
- Released in September 2013
- Integrates H_2incidents.org and H_2bestpractices.org into a single, searchable, iPad and iPhone application
- Features include safety planning guidance and checklists
- All tools (except H_2incidents.org) are available without a data connection

941 Downloads as of 05/2014

By Platform



By Territory



Hydrogen Tools

A Transformative Step Towards Hydrogen Adoption

CENTRALIZED LOCATION — organizes current H_2 resources in one robust location—including **more than 20** existing tools, with plans for adding future content

FOCUSED CONTENT — tailored to the specialized needs of H_2 user groups

CUSTOMIZABLE INTERFACE — allows content to display based on the H_2 user's role or interests

RESPONSIVE DESIGN — enables H_2 safety work across both desktop and mobile devices

TRUSTED COMMUNITIES — fostered through social networking around H_2 subject matter expertise

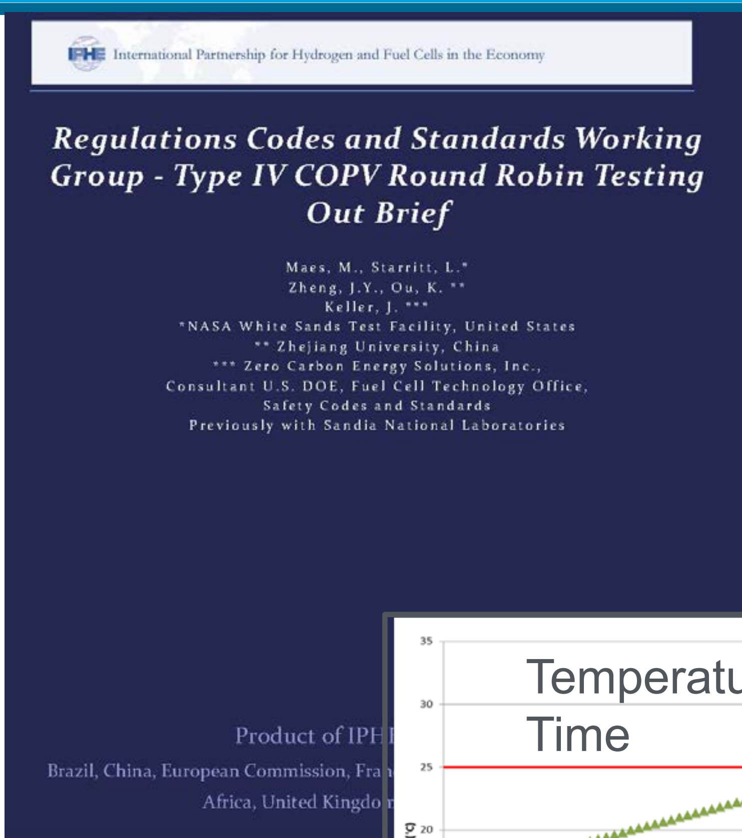
EXPANDABLE FORMAT — built with frequently requested future feature sets in mind

› **Credible** and **reliable** safety information from a **trustworthy** source

Collaboration: IPHE Regulations, Codes and Standards Working Group

U.S. DEPARTMENT OF ENERGY

International round robin testing of Type IV tanks successfully completed using a harmonized test measurement protocol

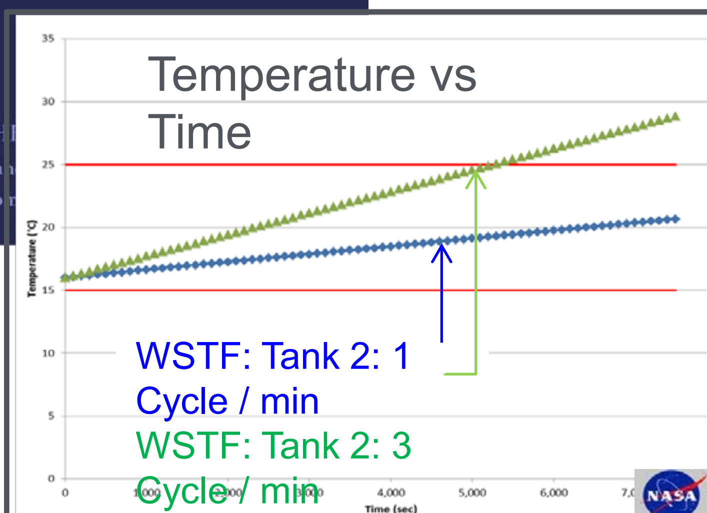

International Partnership for Hydrogen and Fuel Cells in the Economy

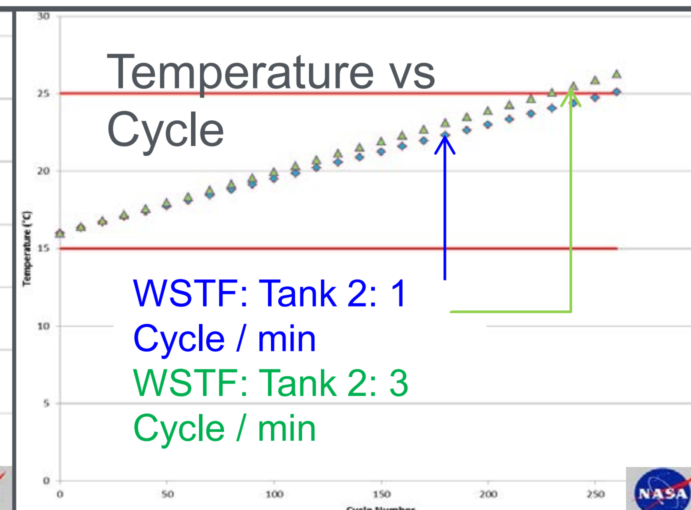
Regulations Codes and Standards Working Group - Type IV COPV Round Robin Testing Out Brief

Maes, M., Starritt, L.*
Zheng, J.Y., Ou, K. **
Keller, J. ***
*NASA White Sands Test Facility, United States
** Zhejiang University, China
*** Zero Carbon Energy Solutions, Inc.,
Consultant U.S. DOE, Fuel Cell Technology Office,
Safety Codes and Standards
Previously with Sandia National Laboratories

Product of IPH
Brazil, China, European Commission, Fra
Africa, United Kingdo

- Execute hydraulic cycle test representative of proposed requirements for composite overwrapped pressure tanks (i.e, SAE J2579, GTR, EIHP Rev 12B)
- Determined temperature increase is system dependent
  - Temperature increase on a per cycle basis is roughly independent of cycle rate (every thing else being constant)
  - Upper temperature limit reached after about ~250 cycles
- **Final Report Submitted to the IPHE SC at the May 20-21 Spring Meeting.**





Key Webinars, Reports, and Workshops

U.S. DEPARTMENT OF ENERGY

Webinars

1st Bilateral International Webinar – Jointly between U.S. and E.C. held in conjunction with ICHS5
What Can We Learn From Hydrogen Safety Event Databases? (Sept 10, 2013)
Will James (DOE), Steve Weiner (PNNL), and Pietro Moretto (JRC)
http://energy.gov/eere/fuelcells/downloads/what-can-we-learn-hydrogen-safety-event-databases

ICHS International Conference on Hydrogen Safety

Hydrogen Compatibility of Materials (August 13, 2013)
Chris San Marchi, Sandia National Laboratory
http://energy.gov/eere/fuelcells/downloads/hydrogen-compatibility-materials

Key Reports

Polymers for Hydrogen Infrastructure and Vehicle Fuel Systems: Applications, Properties, and Gap Analysis (Sandia National Laboratory) – October 2013 (w/Delivery Program)
Rachael Barth, Kevin Simmons (PNNL), and Chris San Marchi


SANDIA REPORT

Safety, Codes and Standards for Hydrogen Installations: Hydrogen Fueling System Footprint Metric Development

Safety, Codes and Standards for Hydrogen Installations: Hydrogen Fueling System Footprint Metric Development (Sandia National Laboratory) – April 2014
Aaron Harris, Daniel Dedrick, Chris LaFluer, and Chris San Marchi

Workshop

Hydrogen Quantitative Risk Assessment Workshop – co-hosted by SNL and IA HySafe
June 11-12, 2013 in Washington, D.C.

hySafe INTERNATIONAL ASSOCIATION FOR HYDROGEN SAFETY

Recent and Upcoming Activities

U.S. DEPARTMENT OF ENERGY

Summary of activities and upcoming milestones

- Define the impact of fast fueling (SAE standard J2601) on hydrogen station requirements.
- Quantify the impact of liquid hydrogen release to help define reduced separation distances outlined in NFPA 2/55 from the current requirement of 75 feet from vents/openings.
- Develop a hydrogen fueling station template that includes the safety codes necessary for widespread commercialization of infrastructure
- Coordinate with State of California (CEC) to accelerate station deployment
- Determine fuel purity requirements and the impact of cleaners/degreasers for hydrogen components

FY 2014 | **FY 2015** | **FY 2016**

2Q 2014: Publishing of SAE J2601 *Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles*

1Q 2015: Publication of Codes and Standards, Safety peer-reviewed article to the International Journal of Hydrogen Energy

NFPA 2 adopted into the International Fire Code

1Q 2016: 6th Annual International Conference on Hydrogen Safety held in Japan

1Q 20162: 2nd Edition of NFPA 2 *Hydrogen Technologies Code published*

2Q 2016: United States adoption of Global Technical Regulation as the Federal Motor Vehicle Safety Standard (FMVSS).

Collaborations

U.S. DEPARTMENT OF ENERGY

External Input

- Annual Merit Review & Peer Evaluation
- H_2 & Fuel Cell Technical Advisory Committee
- National Academies, GAO, etc.

International

- International Partnership for Hydrogen & Fuel Cells in the Economy
  – 17 countries & EC, 30 projects
- Independent Projects (EU, Japan, Korea, etc)

Federal Agencies

DOT NASA

– *Interagency coordination through staff-level Interagency Working Group (meets monthly)*
– *Assistant Secretary-level Interagency Task Force mandated by EPACT 2005.*

Safety, Codes and Standards

State & Regional Partnerships

- California Fuel Cell Partnership
- California Stationary Fuel Cell Collaborative
- SC H_2 & Fuel Cell Alliance
- Upper Midwest Hydrogen Initiative
- Ohio Fuel Coalition
- Connecticut Center for Advanced Technology

Industry Partnerships & Stakeholder Assn's.

- Tech Teams (USCAR, energy companies- U.S. DRIVE) – GM, Ford, DOT, CaFCP, Exxon
- Fuel Cell and Hydrogen Energy Association (FCHEA)
- H2USA
- Various CDOs & SDOs (SAE, NFPA, ISO, CSA, ICC, etc)

National Laboratories

Lawrence Livermore
Los Alamos
NREL
Oak Ridge
Pacific Northwest
Sandia
Savannah River

Contacts:

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http://energy.gov/eere/fuelcells/fuel-cell-technologies-office