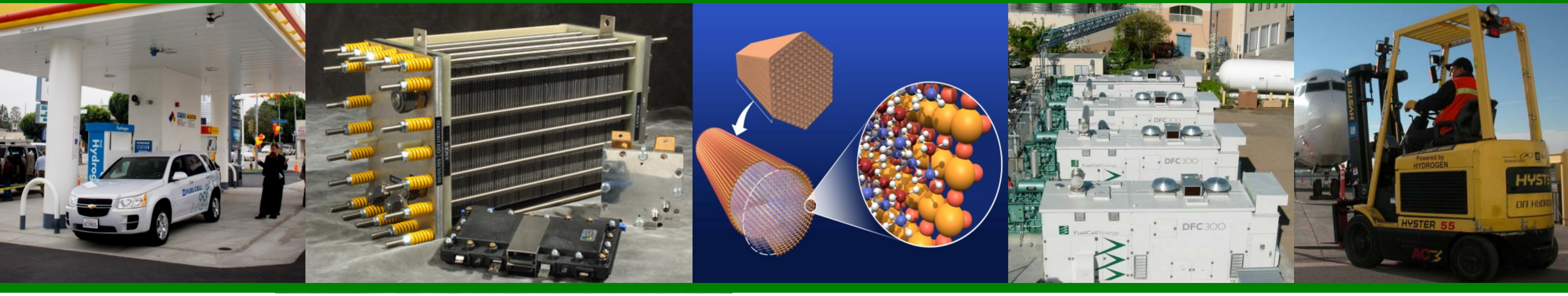
U.S. DEPARTMENT OF
ENERGY



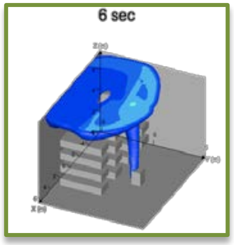
Safety, Codes and Standards
- Session Introduction -

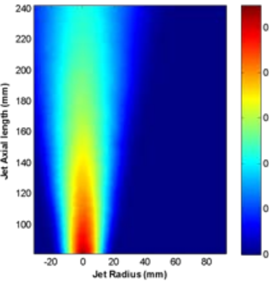
Antonio Ruiz

2012 Annual Merit Review and Peer Evaluation Meeting
May 15, 2012

Goal & Objectives

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





Goals

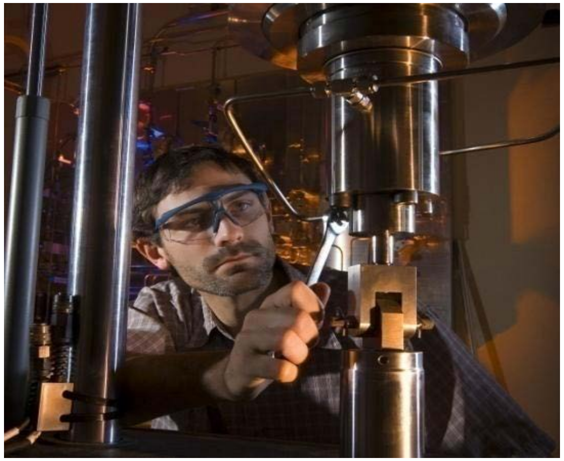
- Develop and implement safety practices and procedures to ensure the safe operation, handling, and use of hydrogen and fuel cell technology
- Conduct critical R&D needed for the development of technically sound codes and standards and facilitate harmonization of domestic and international regulations, codes, and standards.

Objectives

- Ensure the safety of all projects funded by the DOE Fuel Cell Technologies Program
- Make available safety-related information resources and lessons learned with key stakeholders (first responders, regulators, and others)
- Identify and mitigate risk and understand insurability issues for widespread commercialization.
- Conduct R&D to provide critical data and information needed to define requirements in developing codes and standards.
- Develop and validate appropriate test methodologies for certifying hydrogen and fuel cell systems and components.

Challenges

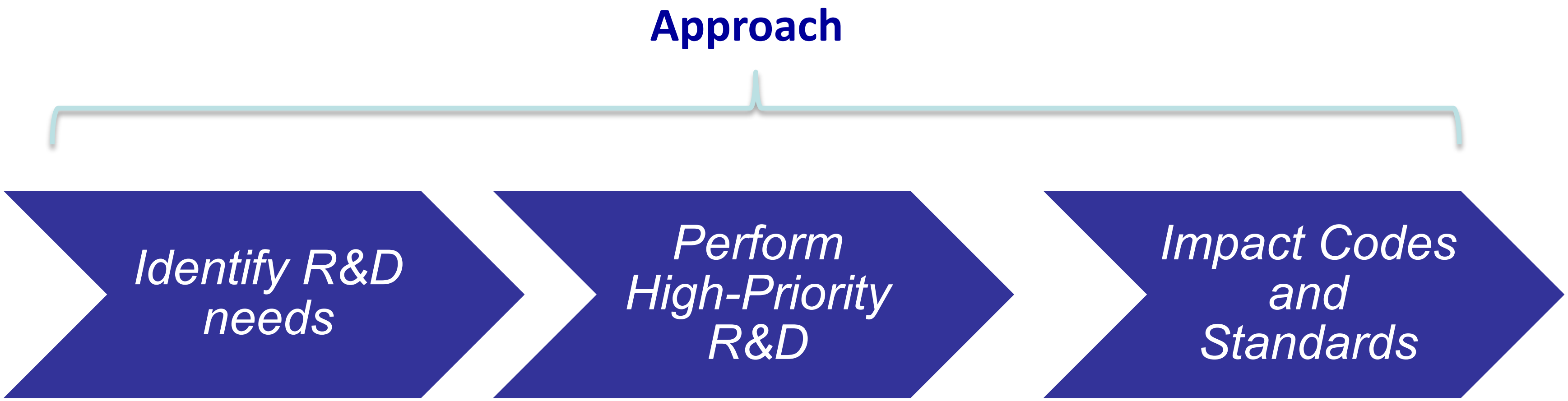
Lack of data needed for the development of critical codes and standards to enable the widespread commercialization of hydrogen and fuel cell technologies



Lack of…

- Synchronized codes and standards development and adoption with technology deployment and commercialization needs
- Coordination of R&D with codes and standards development cycle and revision schedule
- Domestic and international harmonization
- Adoption of the latest developed codes and standards
- Standardization of the permitting process for hydrogen infrastructure
- Data and hydrogen safety information (e.g., best practices and frequency data)
- Readily available training material for first responders and other key stakeholders

Overview



Approach

Identify R&D needs

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

Perform High-Priority R&D

- Understand foundational hydrogen behavior
- Quantitative Risk Assessments
- Compatible materials and components
- Develop and harmonize test protocols

Impact Codes and Standards

- Participate in and lead technical committees to develop requirements
- Publish R&D results

Harmonize Internationally

Global Technical Regulations (GTR Phase 1-SAE J2578, SAE J2579)
International Standards Development Organizations(e.g., ISO, IEC)
International Partnerships and Agreements (IPHE, IEA)

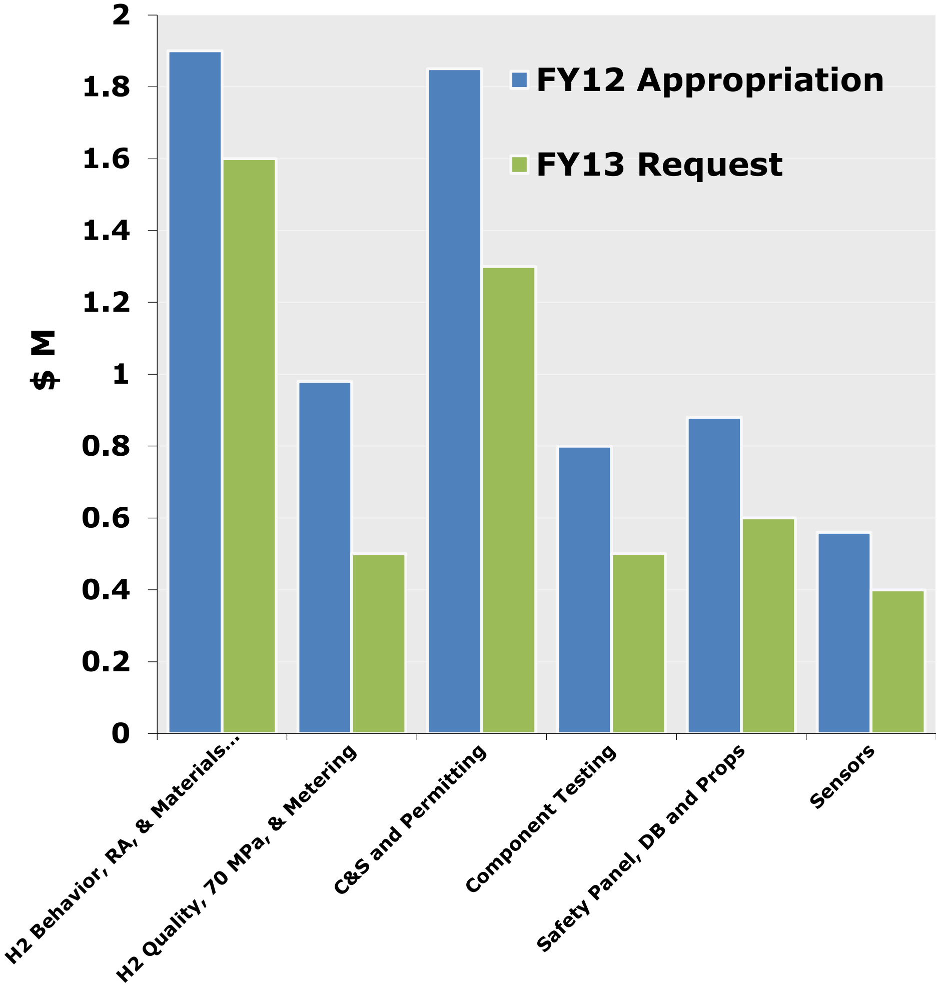
Budget

U.S. DEPARTMENT OF ENERGY

FY 2013 Request Allows for Continued Emphasis on Critical RCS

FY 2012 Appropriation = $7.0 M

FY 2013 Request = $5.0 M

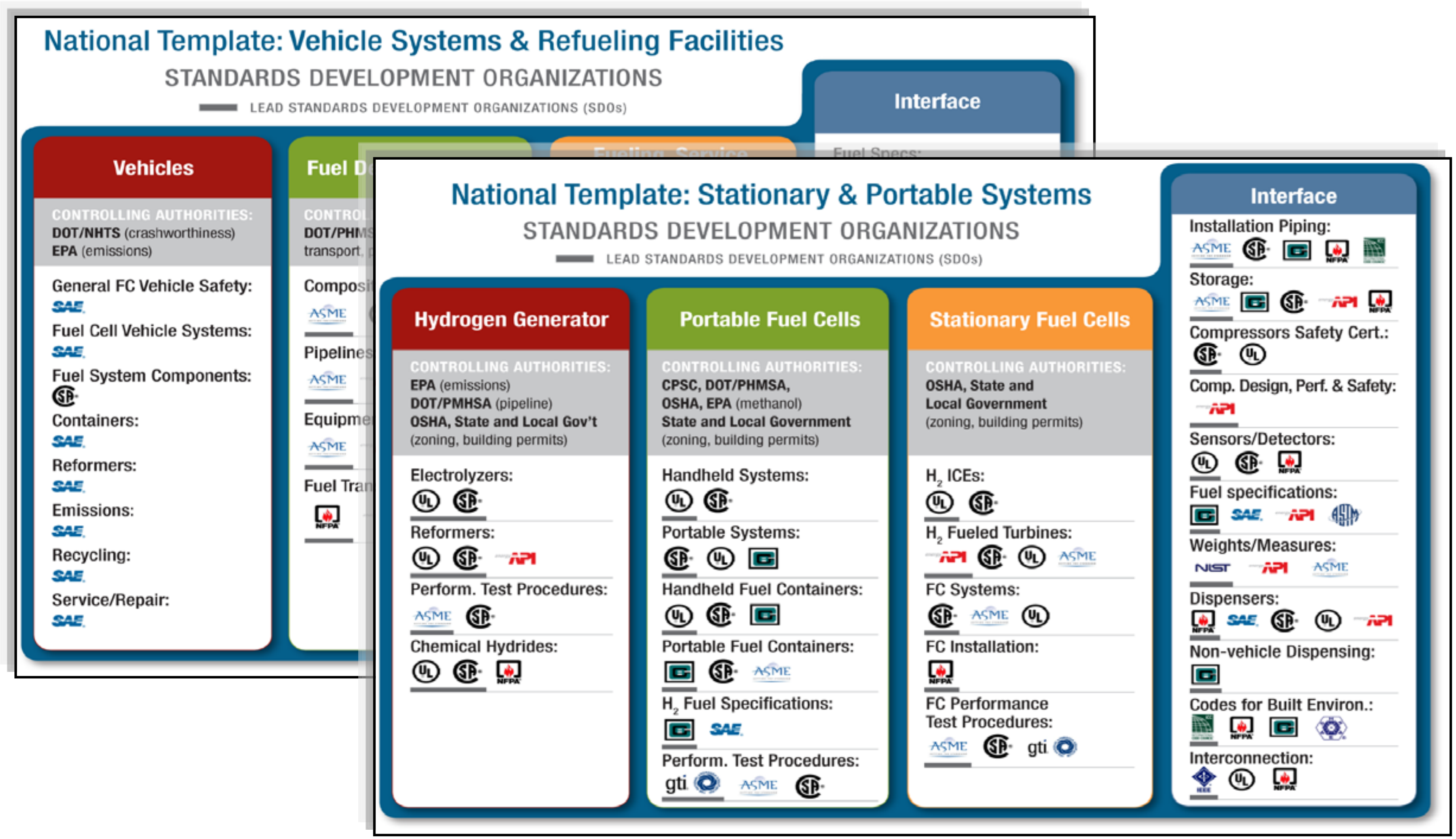


Emphasis:

- Develop technical information and performance data to enhance codes and standards
- Facilitate the permitting of hydrogen fueling stations and early market applications
- Test, measure and verify hydrogen fuel specification
- Assess risks and establish protocols to identify and mitigate risk
- Harmonize test protocols for qualification and certification
- Harmonize hydrogen fuel quality and other key international standards
- Disseminate hydrogen “best practices” and safety information

Progress: National C&S Template

U.S. codes and standards development coordination



National Template: Vehicle Systems & Refueling Facilities

STANDARDS DEVELOPMENT ORGANIZATIONS

LEAD STANDARDS DEVELOPMENT ORGANIZATIONS (SDOs)

Vehicles

CONTROLLING AUTHORITIES:
DOT/NHTS (crashworthiness)
EPA (emissions)

General FC Vehicle Safety: SAE
Fuel Cell Vehicle Systems: SAE
Fuel System Components: CSA
Containers: SAE
Reformers: SAE
Emissions: SAE
Recycling: SAE
Service/Repair: SAE

Fuel D

CONTROL
DOT/PHM
transport

Compos ASME
Pipelines ASME
Equipme ASME
Fuel Tran NFPA

Interface

Fuel Specs:

National Template: Stationary & Portable Systems

STANDARDS DEVELOPMENT ORGANIZATIONS

LEAD STANDARDS DEVELOPMENT ORGANIZATIONS (SDOs)

Hydrogen Generator

CONTROLLING AUTHORITIES:
EPA (emissions)
DOT/PMHSA (pipeline)
OSHA, State and Local Gov't
(zoning, building permits)

Electrolyzers: UL CSA
Reformers: UL CSA API
Perform. Test Procedures: ASME CSA
Chemical Hydrides: UL CSA NFPA

Portable Fuel Cells

CONTROLLING AUTHORITIES:
CPSC, DOT/PHMSA,
OSHA, EPA (methanol)
State and Local Government
(zoning, building permits)

Handheld Systems: UL CSA
Portable Systems: CSA UL
Handheld Fuel Containers: UL CSA
Portable Fuel Containers: CSA ASME
H_2 Fuel Specifications: SAE
Perform. Test Procedures: gti ASME CSA

Stationary Fuel Cells

CONTROLLING AUTHORITIES:
OSHA, State and
Local Government
(zoning, building permits)

H_2 ICEs: UL CSA
H_2 Fueled Turbines: API CSA UL ASME
FC Systems: CSA ASME UL
FC Installation: NFPA
FC Performance Test Procedures: ASME CSA gti

Interface

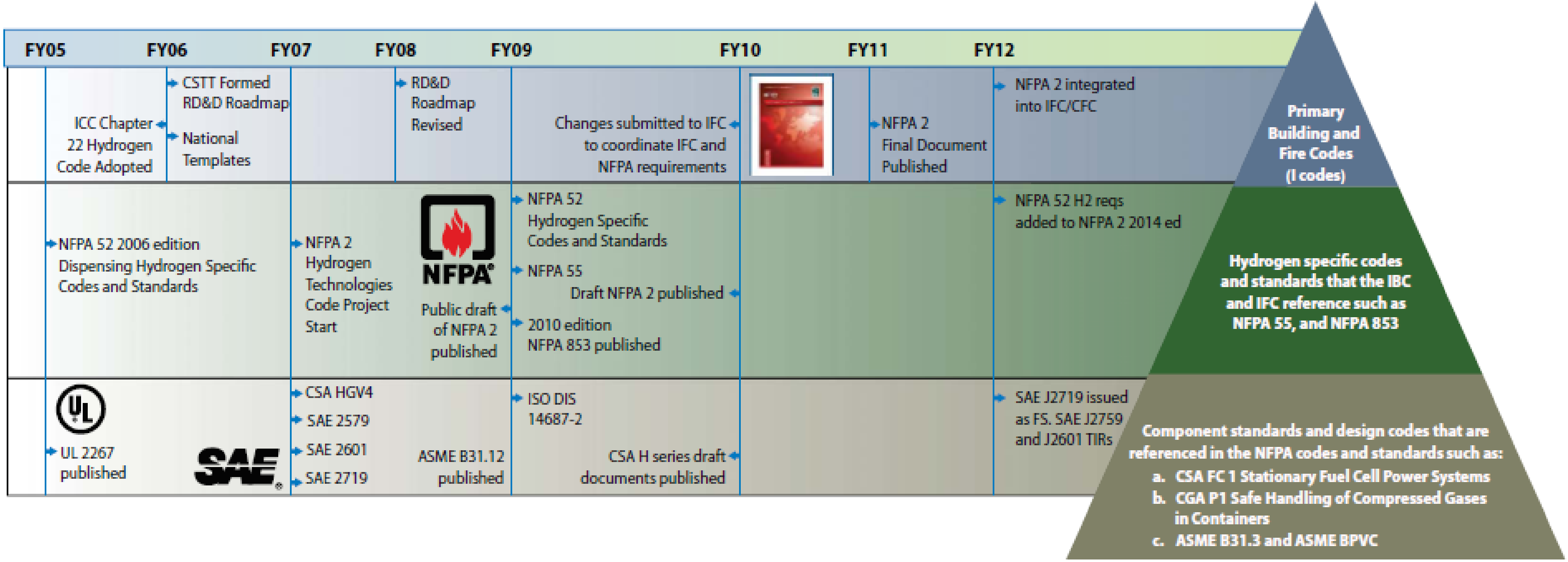
Installation Piping: ASME CSA NFPA
Storage: ASME CSA API NFPA
Compressors Safety Cert.: CSA UL
Comp. Design, Perf. & Safety: API
Sensors/Detectors: UL CSA NFPA
Fuel specifications: SAE API ASTM
Weights/Measures: NIST API ASME
Dispensers: NFPA SAE CSA UL API
Non-vehicle Dispensing:
Codes for Built Environ.: NFPA
Interconnection: IEEE UL NFPA

- *National template to delineate and coordinate critical roles of standards and model code development organizations*

www1.eere.energy.gov/hydrogenandfuelcells/codes/standards_organization.html

Progress: Safety, Codes & Standards

Timeline of Hydrogen Codes and Standards



FY05 FY06 FY07 FY08 FY09 FY10 FY11 FY12

ICC Chapter 22 Hydrogen Code Adopted

CSTT Formed RD&D Roadmap

National Templates

RD&D Roadmap Revised

Changes submitted to IFC to coordinate IFC and NFPA requirements

NFPA 2 Final Document Published

NFPA 2 integrated into IFC/CFC

NFPA 52 2006 edition Dispensing Hydrogen Specific Codes and Standards

NFPA 2 Hydrogen Technologies Code Project Start

Public draft of NFPA 2 published

NFPA 52 Hydrogen Specific Codes and Standards

NFPA 55

Draft NFPA 2 published

2010 edition NFPA 853 published

NFPA 52 H2 reqs added to NFPA 2 2014 ed

UL 2267 published

CSA HGV4

SAE 2579

SAE 2601

SAE 2719

ASME B31.12 published

ISO DIS 14687-2

CSA H series draft documents published

SAE J2719 issued as FS. SAE J2759 and J2601 TIRs

Primary Building and Fire Codes (I codes)

Hydrogen specific codes and standards that the IBC and IFC reference such as NFPA 55, and NFPA 853

Component standards and design codes that are referenced in the NFPA codes and standards such as:

a. **CSA FC 1 Stationary Fuel Cell Power Systems**
b. **CGA P1 Safe Handling of Compressed Gases in Containers**
c. **ASME B31.3 and ASME BPVC**

Examples of Accomplishments:

- Demonstrated up to 50,000 refuelings of metals tanks for forklift applications
- Provided technical data and incorporated a risk-informed approach that enabled NFPA2 to update bulk gas storage separation distances
- Launched international round robin testing of Type IV tanks
- Implemented a science-based approach to develop an ISO standard for hydrogen fuel quality (standard approved).
- Completed R&D to enable Test Method for Evaluating Materials Compatibility standard.

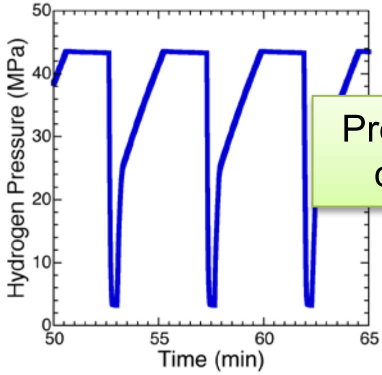
Developed training material for first responders, code officials.
> 23,000 to-date (online & in-person)

The United States will use the GTR as the technical underpinning for the development of the U.S. Federal Motor Vehicle Safety Standard (FMVSS). Submitted to the U.N. ECE WP29 Dec. 2011, Target Acceptance Dec. 2012

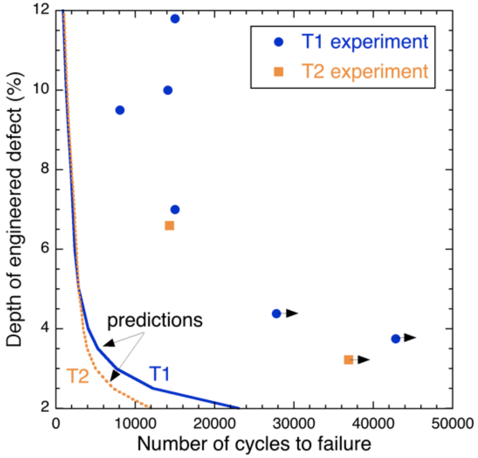
Accomplishment

Full-scale pressure vessel testing supports CSA HPIT1 standard development.

- Engineered defects used to evaluate defect tolerance
- Vessels cycled to failure or up to 50,000 cycles
- Cycle-life compared to ASME design calculations for hydrogen pressure vessels
- Materials testing in gaseous hydrogen also performed
- All observed failures were leak-before-break
- Cycle-life calculations (with engineered defects) are conservative by factor of 4 or more
- Results used to justify design requirements in CSA HPIT1 standard



Pressure cycle



Proposed design requirements

- Quench and tempered Cr-Mo steels
- S_u (ultimate strength) ≤ 890 MPa
- hoop stress ≤ 0.4 S_u

Approach

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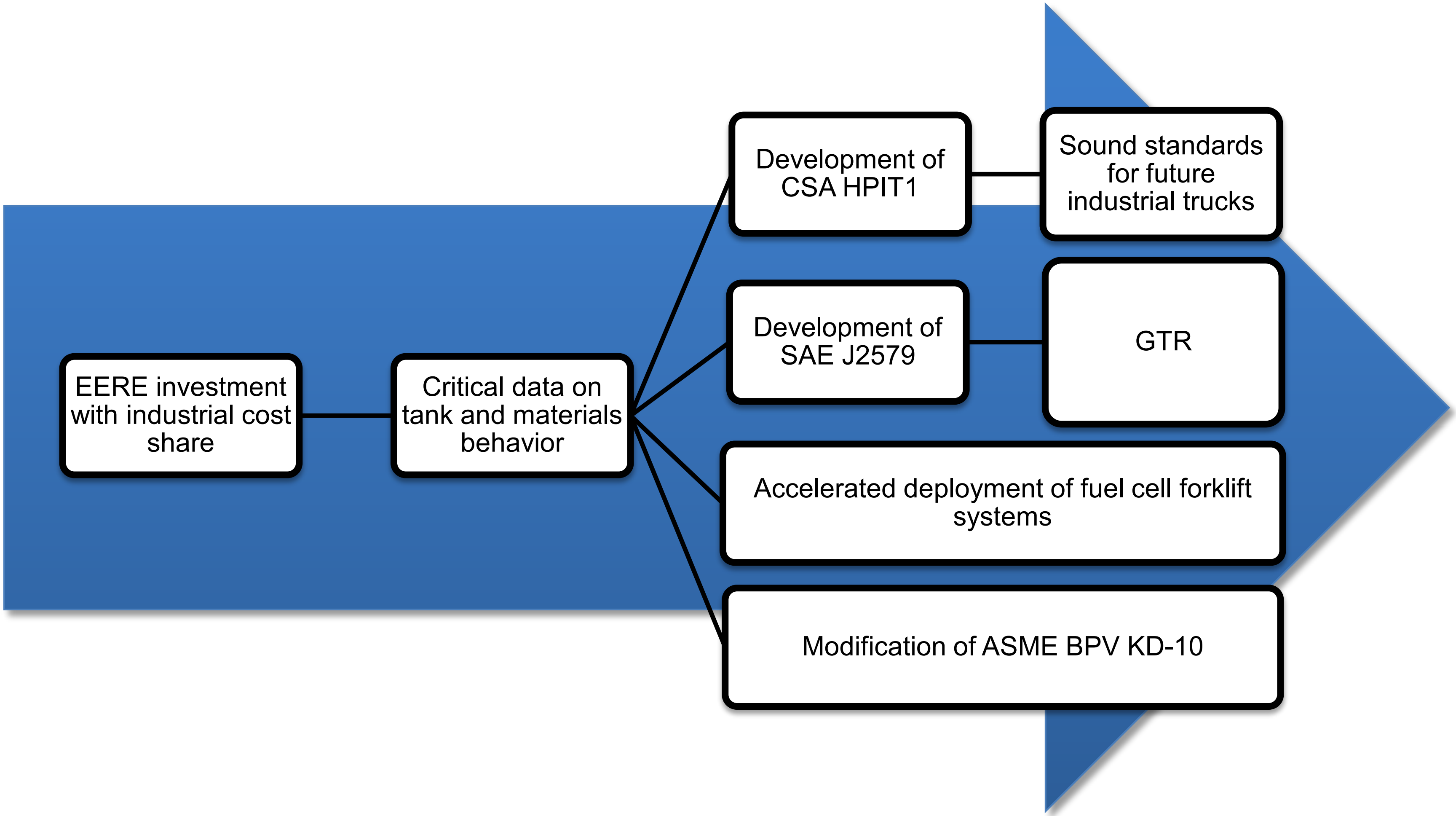
Strategic pathway for impacting standards development



EERE investment with industrial cost share

Critical data on tank and materials behavior

Development of CSA HPIT1

Sound standards for future industrial trucks

Development of SAE J2579

GTR

Accelerated deployment of fuel cell forklift systems

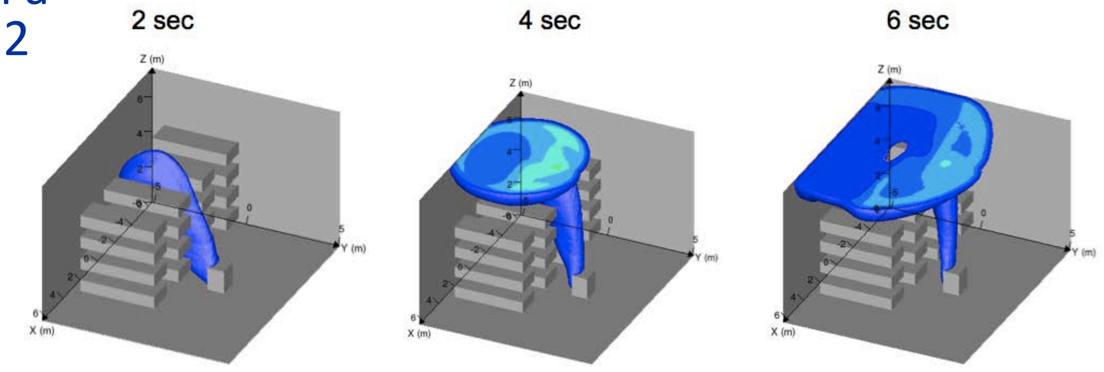
Modification of ASME BPV KD-10

Progress: Indoor Refueling

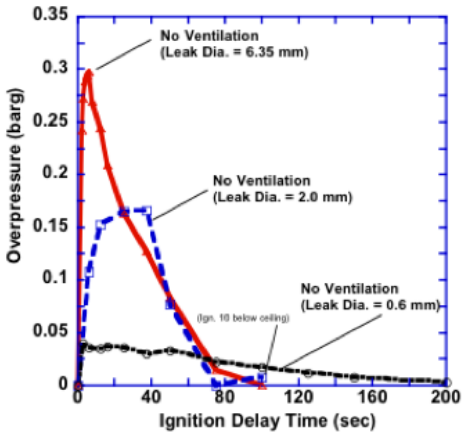
Will provide indoor releases data and analysis to advance NFPA 2 (2014 Edition)

- Evaluated H2 releases (0.8 kg) in a room-volume specified in NFPA 2
- Numerical experiments performed to understand effect of:
  - Leak size
  - Ignition delay
  - Ventilation
  - Obstacles
- Results are being incorporated into a fault-tree model of indoor refueling systems

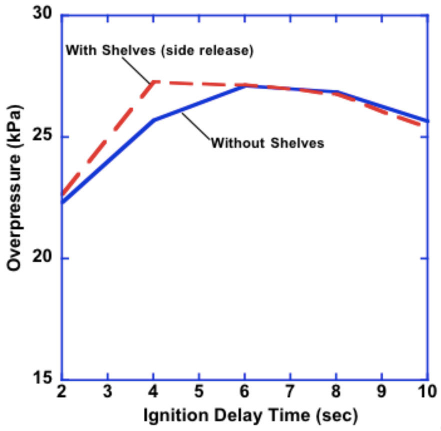
Flammable volume as a function of time for 6.35mm leak



Overpressure as a function of leak size



Overpressure with and w/o obstacles



Sandia National Laboratories

Progress: Releases in Semi-enclosures

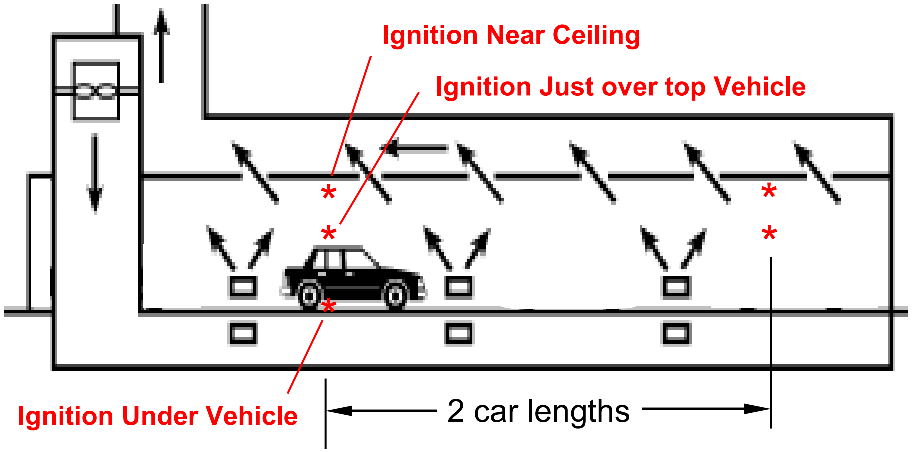
Release scenarios will allow for harmonization of NFPA 2 and NFPA 502.

- Conducted H2 releases in transversely-ventilated tunnels
- Assumed full release through the FCEV TPRD
- Numerical experiments performed to understand effect of:
  - Ignition delay
  - Ignition location
  - Ventilation

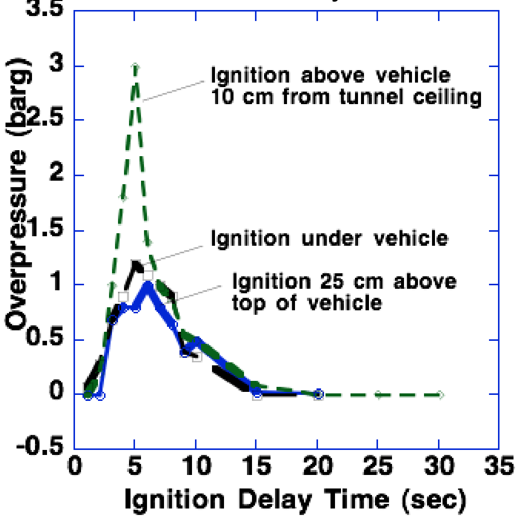
Example results:

- Overpressure lower with no tunnel ventilation
- Pressure highest when ignition occurs near ceiling
- Comparisons made to CNG: potential energy release is actually higher for CNG

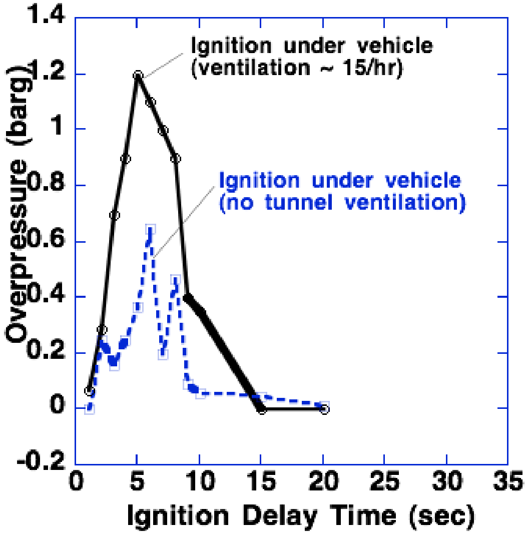
Case: Transversely-Ventilated Tunnel



Effect of Moving Ignition Point Vertically



Effect of Ventilation



Progress: IPHE RCS WG Round Robin

International RR Tank Test Measurement Effort Launched in FY2011

- Endorsed by the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)

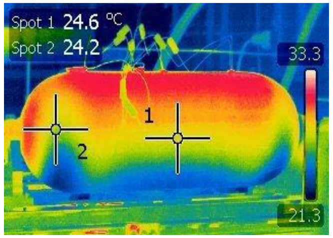
- Round Robin
  - establish detailed measurement *protocol* to ensure global uniformity of test results
  - protocol will focus on validating methods of measuring relevant physics needed to execute the appropriate qualifying test sequences for high pressure composite overwrap tanks (e.g., pressure ramp rates and hold duration, temperature control, etc.)
  - Active Members: China, EC, France, U.S.

- Action Plan
  - Execute hydraulic cycling tests in the United States and China
  - Establish internationally harmonized test measurements
  - Validate test measurement for a pneumatic cycle test

Publish the RR results and make available to SDOs

Code and Standard Impact

Fast-Fill Model Validation (SNL,China):



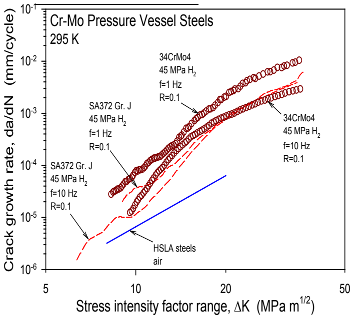
Motivation

- A variety fill models exist, some proprietary
- A generalized, validated model provides a comparative standard
- Current data may be inadequate to fully validate a model
- Current Standards (SAE 2579, GTR, EIHP)

Experimental Approach

- Perform hydrogen filling experiments at specified and relevant pressure ramp rate while the following measurements are made:
  - The transient gas pressure in the tank
  - The total enthalpy of hydrogen entering the tank
  - The transient mass flow rate of hydrogen entering the tank
  - The final uniform temperature and pressure in the tank after fill
  - The transient mass-averaged gas temperature in the tank

Materials Compatability (SNL, Japan):



- Completion of standards through committee leadership and data evaluation
  - CSA HPIT1 completed Sept. 2011
  - CSA CHMC1 (Part 1) published early 2012
  - SAE J2579 progress reported at ICHS conference Sept. 2011
  - ASME KD-10
- I^2CNER - Sandia Participation with U. of Illinois and Kyushu University
  - Leverage 40+ years in H_2 Effects on structural materials at SNL
- Evaluate effects of load-cycle frequency on fatigue crack growth rates for 7XXX aluminum alloys in high-pressure H_2
  - Results presented at ASME PVP conference July 2011

Fuel Quality (LANL):

ISO TC 197 Working Group 12

- FDIS Draft Submitted in Nov 2011
- Fuel Quality Technical Report in draft (*Target – Dec 2012)*

SAE J2719

- Hydrogen Quality Guidelines for Fuel Cell Vehicles (Published Sept 2011)

ASTM (D7653-10)

- Determination of Trace Gaseous Contaminants in Hydrogen Fuel by Fourier Transform Infrared (FTIR) Spectroscopy

Sensors (NREL, LANL, LLNL, & EC):

- Working group participation on national and international sensor test standards
  - ISO
  - UL
  - FM
- International Collaboration (NREL/JRC-IET) MOU
  - Oxygen dependence
  - Assess improvements/degradations MEMs sensor
    - Team expanded to include Univ. of Quebec
  - Hydrogen detection via oxygen displacement

Progress: Safety Training

> 23,000 people educated through on-line and classroom courses

Hydrogen Properties and Behaviors

This prop provides a side-by-side demonstration of the flame characteristics of hydrogen and propane. It consists of two burners fed by two cylinders. One cylinder contains gaseous hydrogen and the other contains liquid propane. The gas pressures and flows have been adjusted to make the flames similar in size.

Temperatures at the base of each flame and at the top of each flame are measured using thermocouples, allowing us to compare the relative temperatures of hydrogen and propane flames.

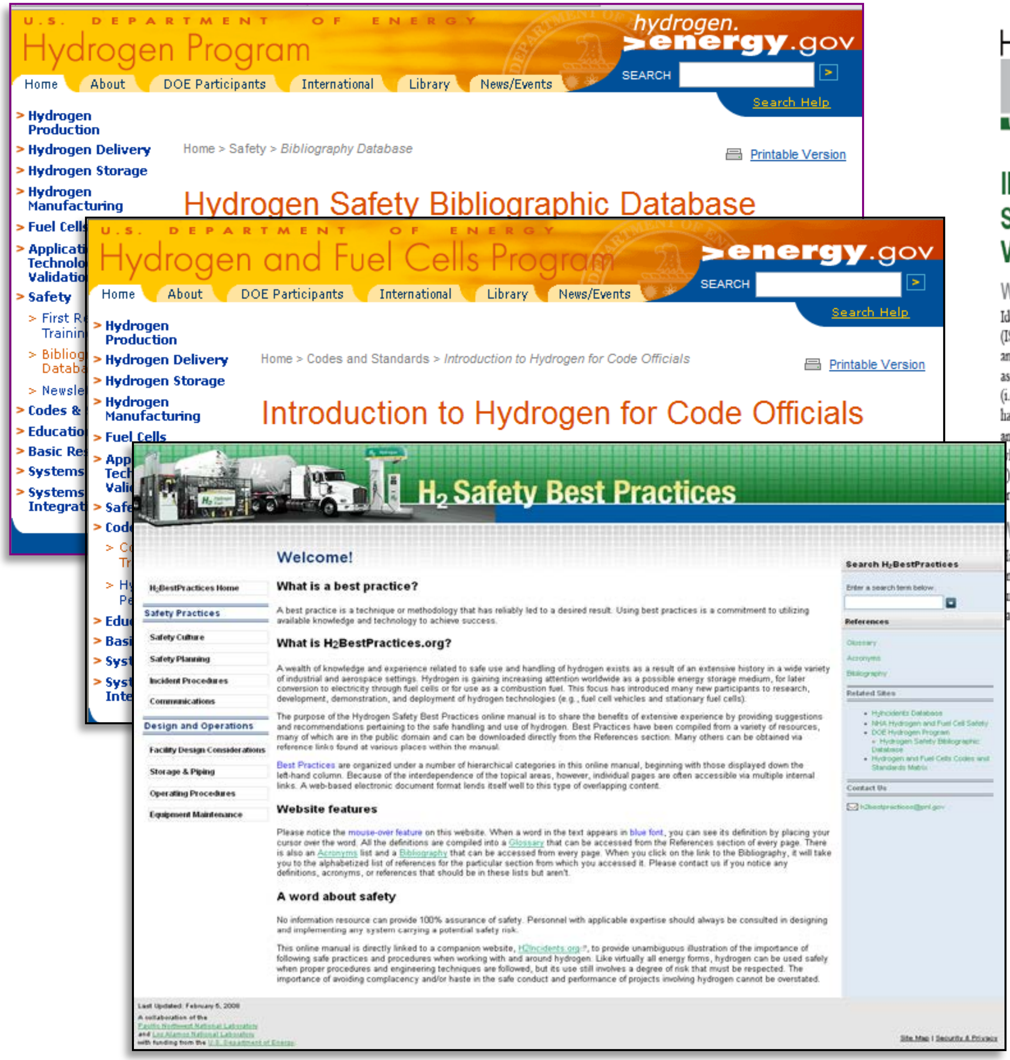
Here we have the propane and hydrogen flames burning on a bright sunny day. The orange propane flame is clearly visible – the hydrogen flame is nearly invisible. But when we look at the flames through a thermal imaging camera, we can see both flames clearly.

A pure hydrogen flame has low radiant heat (mention readings) – much less than the amount

www.hydrogen.energy.gov/firstresponders.html

Hands-on Training for First Responders **Trained 710**	**1-day classroom and live-fire training for fire officials utilizing a fuel cell vehicle prop that demonstrates hydrogen and propane fires**
Basic Hydrogen Education for First Responders **Trained > 21,000**	Understanding basic hydrogen characteristics and behavior for various applications and emergency response protocol
Hydrogen Safety Training for Researcher and Technical Personnel **Trained 100**	On-line basic training on hydrogen pressure safety for researchers conducting laboratory experiments. Providing a comprehensive hands-on training on all aspects of hydrogen systems.
Code Official Training Workshop **Trained 350 (in-person) and 1000 (online)**	Workshops are designed to make information available to expedite the process for developing and permitting fuel cell and hydrogen technology projects. The target area has mostly been in Los Angeles, California.

Progress: Safety Knowledge Tools



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- Hydrogen Delivery
- Hydrogen Storage
- Hydrogen Manufacturing
- Fuel Cells
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Home > Safety > *Bibliography Database*

Hydrogen Safety Bibliographic Database

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Home > Codes and Standards > *Introduction to Hydrogen for Code Officials*

Introduction to Hydrogen for Code Officials

H_2 Safety Best Practices

- H_2BestPractices Home
- **Safety Practices**
  - Safety Culture
  - Safety Planning
  - Incident Procedures
  - Communications
- **Design and Operations**
  - Facility Design Considerations
  - Storage & Piping
  - Operating Procedures
  - Equipment Maintenance

Welcome!

What is a best practice?

A best practice is a technique or methodology that has reliably led to a desired result. Using best practices is a commitment to utilizing available knowledge and technology to achieve success.

What is H_2BestPractices.org?

A wealth of knowledge and experience related to safe use and handling of hydrogen exists as a result of an extensive history in a wide variety of industrial and aerospace settings. Hydrogen is gaining increasing attention worldwide as a possible energy storage medium, for later conversion to electricity through fuel cells or for use as a combustion fuel. This focus has introduced many new participants to research, development, demonstration, and deployment of hydrogen technologies (e.g., fuel cell vehicles and stationary fuel cells).

The purpose of the Hydrogen Safety Best Practices online manual is to share the benefits of extensive experience by providing suggestions and recommendations pertaining to the safe handling and use of hydrogen. Best Practices have been compiled from a variety of resources, many of which are in the public domain and can be downloaded directly from the References section. Many others can be obtained via reference links found at various places within the manual.

Best Practices are organized under a number of hierarchical categories in this online manual, beginning with those displayed down the left-hand column. Because of the interdependence of the topical areas, however, individual pages are often accessible via multiple internal links. A web-based electronic document format lends itself well to this type of overlapping content.

Website features

Please notice the mouse-over feature on this website. When a word in the text appears in blue font, you can see its definition by placing your cursor over the word. All the definitions are compiled into a Glossary that can be accessed from the References section of every page. There is also an Acronyms list and a Bibliography that can be accessed from every page. When you click on the link to the Bibliography, it will take you to the alphabetized list of references for the particular section from which you accessed it. Please contact us if you notice any definitions, acronyms, or references that should be in these lists but aren't.

A word about safety

No information resource can provide 100% assurance of safety. Personnel with applicable expertise should always be consulted in designing and implementing any system carrying a potential safety risk.

This online manual is directly linked to a companion website, H2Incidents.org, to provide unambiguous illustration of the importance of following safe practices and procedures when working with and around hydrogen. Like virtually all energy forms, hydrogen can be used safely when proper procedures and engineering techniques are followed, but its use still involves a degree of risk that must be respected. The importance of avoiding complacency and/or haste in the safe conduct and performance of projects involving hydrogen cannot be overstated.

Search H_2BestPractices

Enter a search term below

References

- Glossary
- Acronyms
- Bibliography

Related Sites

- H2Incidents Database
- NHA Hydrogen and Fuel Cell Safety
- DOE Hydrogen Program
  - Hydrogen Safety Bibliographic Database
- Hydrogen and Fuel Cells Codes and Standards Matrix

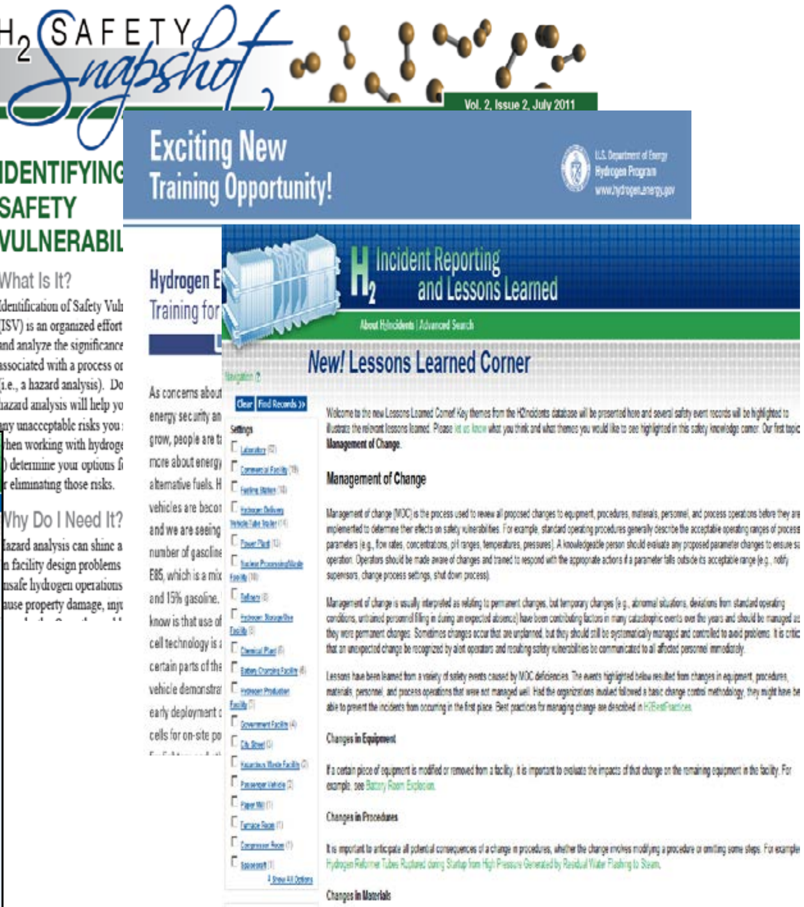
Contact Us

h2bestpractices@pnl.gov

Last Updated: February 5, 2008

A collaboration of the Pacific Northwest National Laboratory and Los Alamos National Laboratory with funding from the U.S. Department of Energy

Site Map | Security & Privacy



IDENTIFYING SAFETY VULNERABIL

What Is It?

Identification of Safety Vul
(ISV) is an organized effort
and analyze the significance
associated with a process or
(i.e., a hazard analysis). Do
hazard analysis will help yo
any unacceptable risks you
hen working with hydroge
) determine your options f
r eliminating those risks.

Why Do I Need It?

azard analysis can shine a
n facility design problems
nsafe hydrogen operations
ause property damage, inju

Exciting New Training Opportunity!

Hydrogen E
Training for

As concerns abou
energy security an
grow, people are t
more about energy
alternative fuels. H
vehicles are becor
and we are seeing
number of gasoline
E85, which is a mix
and 15% gasoline.
know is that use of
cell technology is
certain parts of the
vehicle demonstra
early deployment
cells for on-site po

New! Lessons Learned Corner

Welcome to the new Lessons Learned Corner! Key themes from the H2Incidents database will be presented here and several safety event records will be highlighted to illustrate the relevant lessons learned. Please let us know what you think and what themes you would like to see highlighted in this safety knowledge corner. Our first topic **Management of Change**.

Management of Change

Management of change (MOC) is the process used to review all proposed changes to equipment, procedures, materials, personnel, and process operations before they are implemented to determine their effects on safety vulnerabilities. For example, standard operating procedures generally describe the acceptable operating ranges of process parameters (e.g., flow rates, concentrations, pH ranges, temperatures, pressures). A knowledgeable person should evaluate any proposed parameter changes to ensure sa operation. Operators should be made aware of changes and trained to respond with the appropriate actions if a parameter falls outside its acceptable range (e.g., notify supervisors, change process settings, shut down process).

Management of change is usually interpreted as relating to permanent changes, but temporary changes (e.g., abnormal situations, deviations from standard operating conditions, untrained personnel filling in during an expected absence) have been contributing factors in many catastrophic events over the years and should be managed as they were permanent changes. Sometimes changes occur that are unplanned, but they should still be systematically managed and controlled to avoid problems. It is critic that an unexpected change be recognized by alert operators and resulting safety vulnerabilities be communicated to all affected personnel immediately.

Lessons have been learned from a variety of safety events caused by MOC deficiencies. The events highlighted below resulted from changes in equipment, procedures, materials, personnel, and process operations that were not managed well. Had the organizations involved followed a basic change control methodology, they might have be able to prevent the incidents from occurring in the first place. Best practices for managing change are described in H2BestPractices.

Changes in Equipment

If a certain piece of equipment is modified or removed from a facility, it is important to evaluate the impacts of that change on the remaining equipment in the facility. For example, see Battery Room Explosion.

Changes in Procedures

It is important to anticipate all potential consequences of a change in procedures, whether the change involves modifying a procedure or omitting some steps. For example Hydrogen Reformer Tubes Ruptured during Startup from High Pressure Generated by Residual Water Flashing to Steam.

Changes in Materials

www.eere.energy.gov/hydrogenandfuelcells/codes/

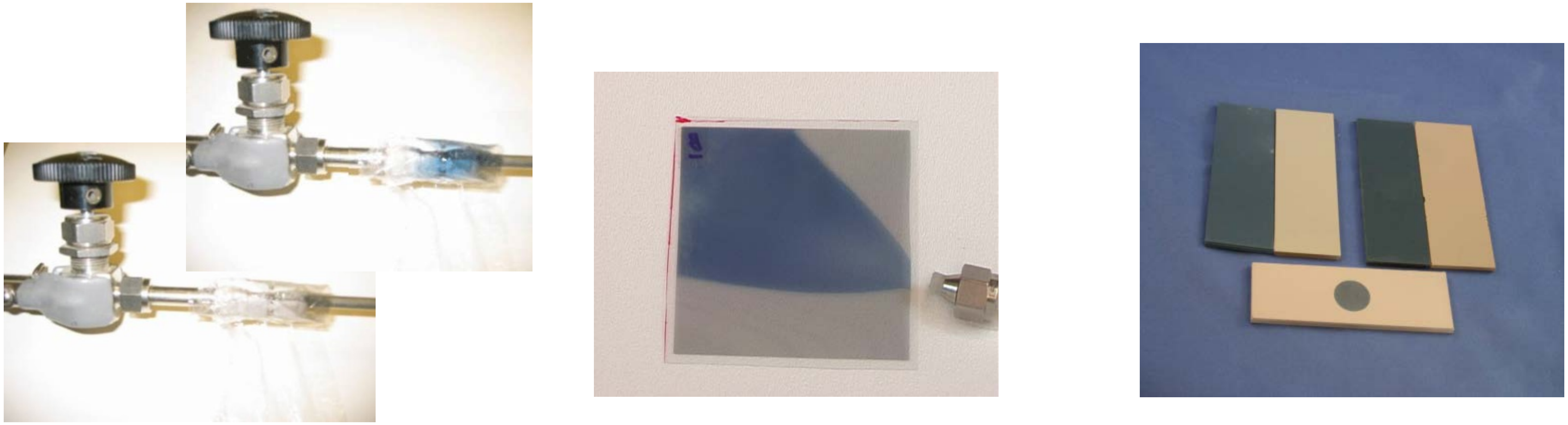
- **206 Lessons Learned events in "H2Incidents.org"**
- **Approximately 750 entries in the Hydrogen Safety Bibliographic Database**

Accomplishment

DOE's America's Next Top Energy Innovator Challenge Runner-up: Element One, Inc.

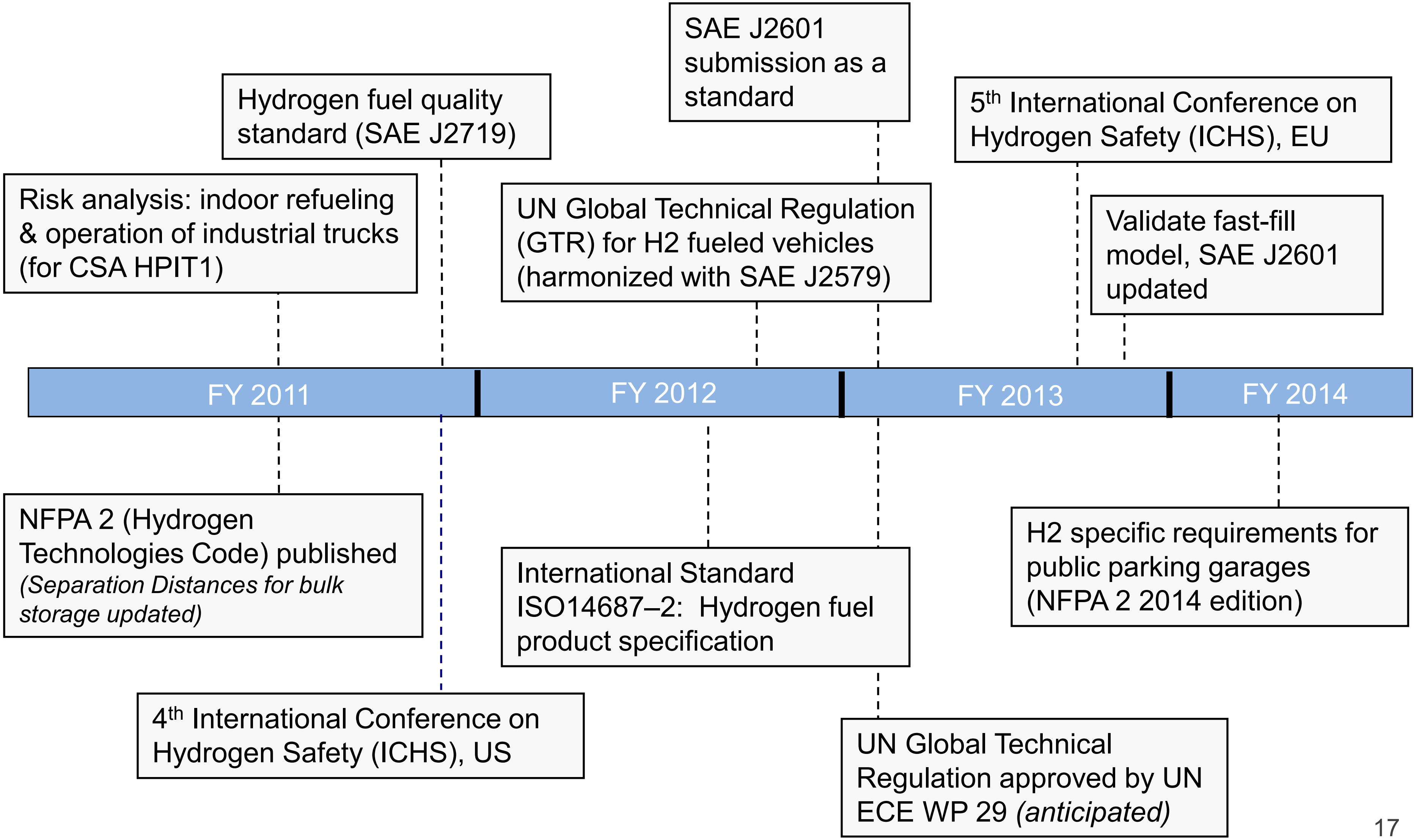
Element One has created revolutionary "smart" coatings for the detection of hydrogen that change color, either reversibly or non-reversibly, to provide both current and historical information about hydrogen leaks.

This makes it possible to produce a wide array of very low-cost, reliable sensors which can be economically deployed at all potential leak sites.



Held April 2, 2012 webinar titled
"Hydrogen leak detection – low cost distributed gas sensors"

Major Roadmap Milestones



Hydrogen fuel quality standard (SAE J2719)

SAE J2601 submission as a standard

5th International Conference on Hydrogen Safety (ICHS), EU

Risk analysis: indoor refueling & operation of industrial trucks (for CSA HPIT1)

UN Global Technical Regulation (GTR) for H2 fueled vehicles (harmonized with SAE J2579)

Validate fast-fill model, SAE J2601 updated

NFPA 2 (Hydrogen Technologies Code) published *(Separation Distances for bulk storage updated)*

International Standard ISO14687–2: Hydrogen fuel product specification

H2 specific requirements for public parking garages (NFPA 2 2014 edition)

4th International Conference on Hydrogen Safety (ICHS), US

UN Global Technical Regulation approved by UN ECE WP 29 *(anticipated)*

Reviewer Reminders

- Deadline to submit your reviews is **May 25th at 5:00 pm EDT.**

- ORISE personnel are available on-site for assistance.
  - **Reviewer Lab Hours:** Tuesday – Thursday, 7:30 am – 8:30 pm; Friday 7:30 am – 1:00 pm.
  - **Reviewer Lab Locations:**
    - Crystal Gateway Hotel—Rosslyn Room (downstairs, on Lobby level)
    - Crystal City Hotel—the Roosevelt Boardroom (next to Salon A)

- Reviewers are invited to a brief feedback session – at 3:45 pm today, in this room.

Session Instructions

- This is a review, not a conference.
- Presentations will begin precisely at scheduled times.
- Talks will be 20 minutes and Q&A 10 minutes.
- Reviewers have priority for questions over the general audience.
- Reviewers should be seated in front of the room for convenient access by the microphone attendants during the Q&A.
- Please mute all cell phones and other portable devices.
- Photography and audio and video recording are not permitted.

For More Information

U.S. DEPARTMENT OF ENERGY

Safety, Codes and Standards

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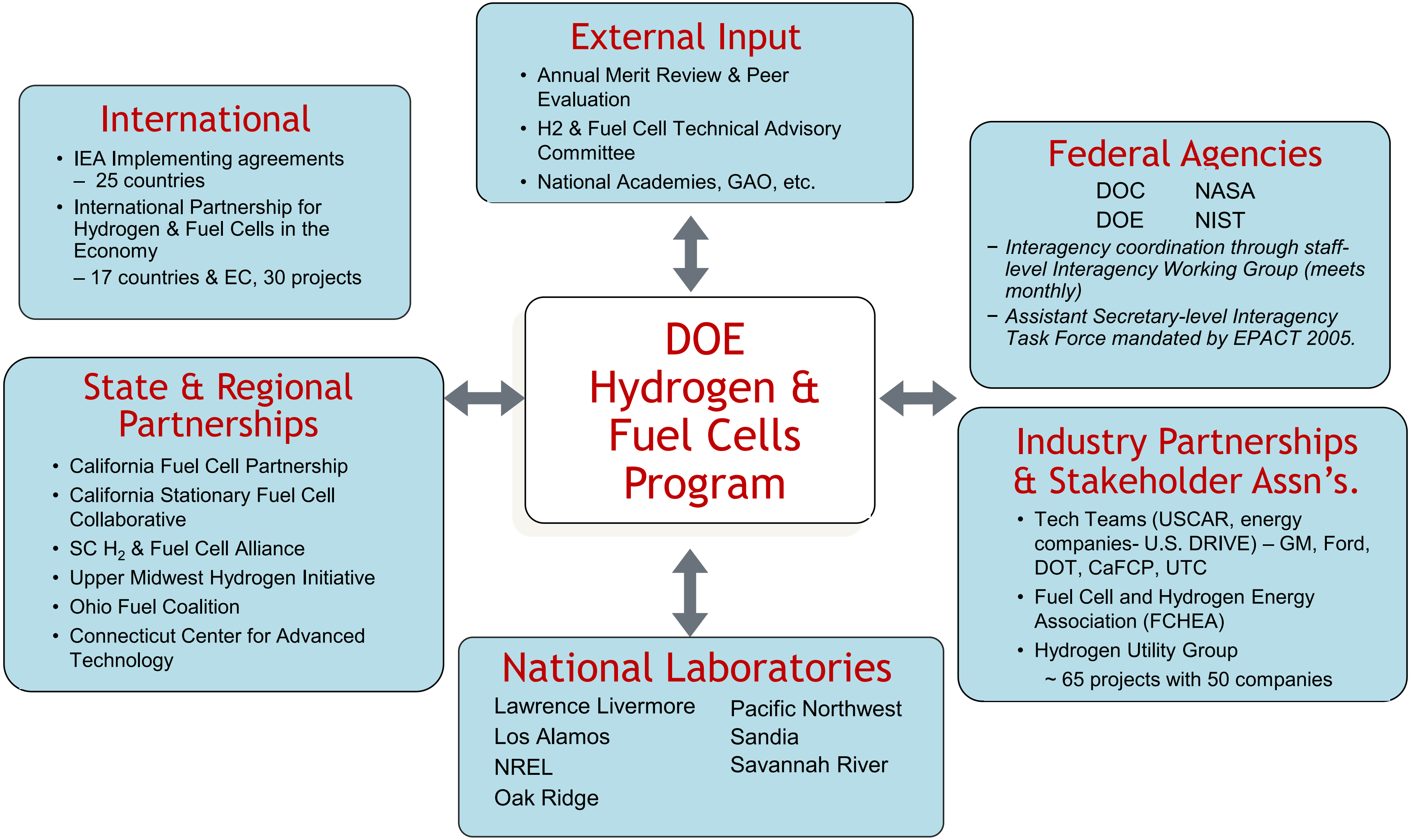
Jim Ohi (Consultant)
Jay Keller (Consultant)

Participating Organizations



External Input

- Annual Merit Review & Peer Evaluation
- H2 & Fuel Cell Technical Advisory Committee
- National Academies, GAO, etc.

International

- IEA Implementing agreements
  - 25 countries
- International Partnership for Hydrogen & Fuel Cells in the Economy
  - 17 countries & EC, 30 projects

Federal Agencies

DOC	NASA
DOE	NIST

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

DOE Hydrogen & Fuel Cells Program

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, UTC
- Fuel Cell and Hydrogen Energy Association (FCHEA)
- Hydrogen Utility Group
  - ~ 65 projects with 50 companies

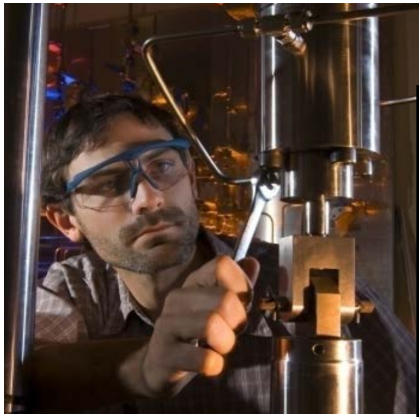
National Laboratories

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

Additional Information

Progress

Materials and Components Compatibility



Technical Reference

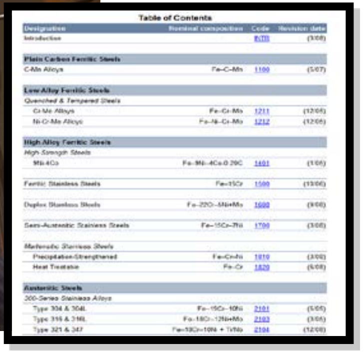


Table of Contents

Designation	Nominal composition	Code	Revision date
Introduction		INTR	(3/08)
Plain Carbon Ferritic Steels			
C-Mn Alloys	Fe–C–Mn	1100	(5/07)
Low-Alloy Ferritic Steels			
Quenched & Tempered Steels			
Cr-Mo Alloys	Fe–Cr–Mo	1211	(12/05)
Ni-Cr-Mo Alloys	Fe–Ni–Cr–Mo	1212	(12/05)
High-Alloy Ferritic Steels			
High-Strength Steels			
9Ni-4Co	Fe–9Ni–4Co–0.20C	1401	(1/05)
Ferritic Stainless Steels	Fe–15Cr	1500	(12/06)
Duplex Stainless Steels	Fe–22Cr–5Ni–Mo	1600	(9/08)
Semi-Austenitic Stainless Steels	Fe–15Cr–7Ni	1700	(3/08)
Martensitic Stainless Steels			
Precipitation-Strengthened	Fe–Cr–Ni	1810	(3/08)
Heat Treatable	Fe–Cr	1820	(6/08)
Austenitic Steels			
300-Series Stainless Alloys			
Type 304 & 304L	Fe–19Cr–10Ni	2101	(5/05)
Type 316 & 316L	Fe–18Cr–12Ni+Mo	2103	(3/05)
Type 321 & 347	Fe–18Cr–10Ni + Ti/Nb	2104	(12/08)

Mechanical load-frame used to characterize H2 effects in materials

Objective

- Enable market transformation through development and application of standards for hydrogen components.
  1. Create materials reference guide
  2. Execute materials testing with an emphasis on steel hydrogen storage tanks
  3. Optimize materials and component test methods to reduce cost while maintaining accuracy
- Participate directly in standards development.
  1. Materials testing standards (ASME Article KD-10, SAE and CSA)
  2. Component/system design qualification standards (CSA HPIT1, CHMC1 and SAE J2579)

Benefits and Challenges

- Address need for technical data to revise standards
- Reduce the cost of materials, component and system qualification
- Develop a materials technical reference
- Develop hydrogen storage tank and component standards for portable, stationary and vehicular use

Approach

- Apply expertise and resources in materials compatibility to implement and improve standards for hydrogen components.
- Project Timeline: October 2003 – September 2015 (58% complete)
- Coordination: Standards development organizations (ASME, CSA, SAE), tank manufactures and forklift integrators (FIBA Technologies, Plug Power, Nuvera FC), DOE Pipeline Working Group and HYDROGENIUS

Key Deliverables and Milestones

- Compare cracking threshold to fracture toughness measurements for vessel steels in hydrogen
- Add/update chapters on nickel-based alloys in “Technical Reference”
- Quantify the effects of load cycle frequency on fatigue of steels in high-pressure hydrogen
- Add/update chapters on ferritic steels in “Technical Reference”
- Report on fatigue crack growth and cracking thresholds of SA372 Gr. J steel in hydrogen

Accomplishments

- Provided technical basis for update of SAE J2579 to include design qualification test (C.14) and materials tests and associated acceptance criteria (C.15)
- Enabled revision of ASME KD-10 tank standard - fracture threshold measurements of tank steels in hydrogen
- Completed materials fatigue testing to enable deployment of 100 MPa stationary tanks
- Updated “Technical Reference for Hydrogen Compatibility of Materials” and data used for materials selection in technology design and for standards development

Progress

U.S. DEPARTMENT OF ENERGY

Quantitative Risk Assessment

Quantitative Risk Assessment helps establish requirements for hydrogen installations

Objective

- Understand the risk associated with hydrogen facilities
- Provide a safe infrastructure for the use of hydrogen through risk management
- Provide risk-informed basis for development of uniform model codes and standards

Benefits and Challenges

- Methods must be developed that accommodate sparse data
- Harmonization of codes and standards requirements allows for international deployment
- Incorporation of risk data helps avoid overly conservative code and standard requirements

Approach

- Use of Quantitative Risk Assessment (QRA) to evaluate risk, identify risk drivers and evaluate mitigation features to establish requirements
- Timeline: October 2003 – September 2015 (60%)
- Coordination: NFPA, ISO, ICC, HIPOC, Air Products

Key Deliverables and Milestones

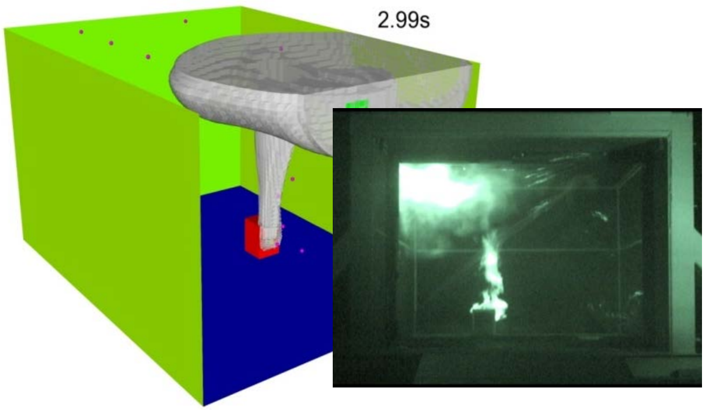
- Complete risk assessment of indoor fuel cell material handling vehicle operations in warehouses
- Develop a consensus hydrogen ignition probability model for use in QRA
- Support NFPA 2 efforts to develop risk informed separation distance tables for LH2 facilities
- Complete risk evaluation of hydrogen refueling stations that utilize LH2, steam reformers or electroyzers

Accomplishments

- Harmonization of NFPA 55 and ISO risk assessment approach, models and data used to establish separation distances
- Risk reduction potential of barriers utilized to establish reduction factor for separation distances in NFPA-55
- Phase I work has been performed on evaluating the risk associated with indoor refueling
    - Development of approaches, models and data required in QRA
    - Experiments performed to understand phenomena, develop models and bench mark consequence models

Progress

Hydrogen Release Behavior



Simulation and experimental validation of release during indoor refueling

Objective

- Provide a defensible and traceable basis for hydrogen codes and standards
- Provide advocacy and technical support for the codes and standards development process

Benefits and Challenges

- Provide expertise and technical data on hydrogen behavior and risk
- Facilitate global harmonization of RCS
- Address insufficient technical data needed to revise standards
- Reduce large footprint requirements for hydrogen fueling stations
- Facilitate safe deployment of renewable energy technologies

Approach

- Develop and validate models for hydrogen behavior to enable risk-informed decision-making for the codes and standards development process
- Project Timeline: October 2003 – September 2015 (60% complete)
- Coordination: SRI, IEA, ICC, NFPA, ISO, NHA, NIST, CTFCA, NREL

Key Deliverables and Milestones

- Understand ignition and dispersion behavior at appropriate temperature and pressure
- Develop and validate engineering models
- Evaluate risk associated with hydrogen indoor refueling
- Evaluate risk associated with small stationary APUs
- Propose risk mitigation methods and quantify risk reduction - achieved

Accomplishments

- Models validated for hydrogen releases in enclosures:
  - Tunnels
  - Warehouses
- Identified mechanism of spontaneous-ignition due to entrained particulates
- Developed the scientific-basis for separation distances in NFPA 55/2
- Harmonized NFPA and ISO framework for specifying separation distances
- Validated the use of barriers to reduce separation distances

Hydrogen Safety Training for First Responders

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

Approach

- Reach first responders via the fuel cell electric vehicle (FCEV) prop-based course, the web-based "Introduction to Hydrogen Safety for First Responders" and outreach to the Fire Department Instructors Conference and Fire Rescue International to raise awareness of hydrogen safety training courses to the target audience.
- Project Timeline: October 2004 – Continuing
- Collaboration: California Fuel Cell Partnership, Hanford Fire Department, and Volpentest Hazardous Materials Management and Emergency Response (HAMMER) Training and Education Center

Key Deliverables and Milestones

- Provide the prop course at Defense Logistics Agency depots and other fire training centers (Summer 2011).
- Continue to update the web-based hydrogen safety course as needed.
- Target outreach opportunities.

Objective

- Support the successful implementation of hydrogen and fuel cell technologies by providing technically accurate hydrogen safety and emergency response information to first responders.
- Continue to provide a one-day first responder training course utilizing DOE's FCEV prop at offsite first responder training centers (civilian and military).
- Continue to support the web-based awareness-level course.
- Disseminate first-responder hydrogen safety educational materials at appropriate conferences to raise awareness.

Barriers Addressed

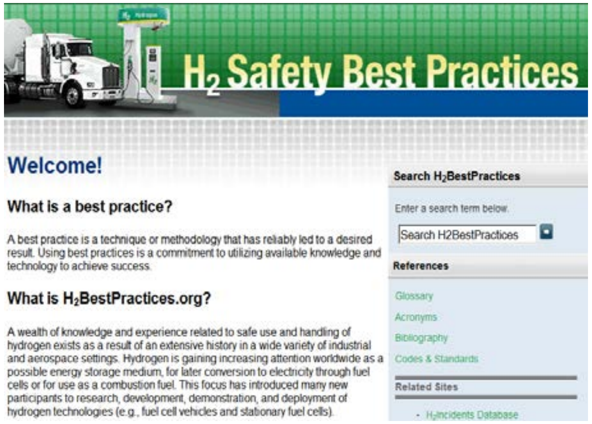
- Lack of readily available, objective, and technically accurate information.
- Disconnect between hydrogen information and dissemination networks.
- Lack of educated trainers and training opportunities.
- Lack of hydrogen knowledge by authorities having jurisdiction.
- Lack of hydrogen safety training facilities for emergency responders.

Accomplishments

- Trained over 300 students in three FCEV prop-based courses in California in August/September 2010.
    - Rio Hondo College Fire Academy, Santa Fe Springs, CA
    - Orange County Fire Authority, Irvine, CA
    - Sunnyvale Department of Public Safety
- Held three sessions of the prop-based course at the HAMMER facility in 2009 and 2010, training ~100 participants from 18 states.
- Web-based course received 18,000 unique visitors and averages 300-400 unique visits each month from every state and many foreign countries.

Progress

Hydrogen Safety Knowledge Tools



Welcome!

What is a best practice?

A best practice is a technique or methodology that has reliably led to a desired result. Using best practices is a commitment to utilizing available knowledge and technology to achieve success.

What is H_2BestPractices.org?

A wealth of knowledge and experience related to safe use and handling of hydrogen exists as a result of an extensive history in a wide variety of industrial and aerospace settings. Hydrogen is gaining increasing attention worldwide as a possible energy storage medium, for later conversion to electricity through fuel cells or for use as a combustion fuel. This focus has introduced many new participants to research, development, demonstration, and deployment of hydrogen technologies (e.g., fuel cell vehicles and stationary fuel cells).

H_2 Safety Best Practices web site (also see H2incidents.org)

Objective

- H2 Safety Best Practices
  Capture vast knowledge base of hydrogen experience and make it publicly available.
- H2 Incident Reporting and Lessons Learned Collect information and share lessons learned from hydrogen incidents and near-misses, with a goal of preventing similar incidents from occurring in the future.

Barriers Addressed

- Limited historical database of incidents
- Proprietary data

Approach

- H2 Safety Best Practices: Best practices are compiled, new Web content is reviewed by the Hydrogen Safety Panel and PNNL experts, and approved material is posted to the Web site.
- H2 Incident Reporting and Lessons Learned: Pursue records and lessons learned for hydrogen incidents and near-miss events to add to the online database.
- Project Timeline: March 2003 – Continuing
- Collaboration: Hydrogen Safety Panel, NASA, LANL, SNL, NREL, IEA Hydrogen Implementing Agreement (HIA) Task 31 and IA HySafe

Key Deliverables and Milestones

- H2 Safety Best Practices
  1. Improve existing and add new content.
  2. Enhance Web site usability.
  3. Encourage use and respond to user questions posted on the Web site.
- H2 Incident Reporting and Lessons Learned
  1. Target to reach > 200 safety event records in FY2011.
  2. Analyze lessons learned from incidents.

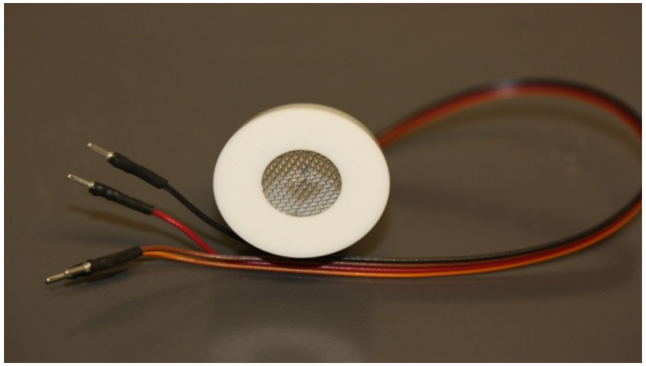
Accomplishments

- H2 Safety Best Practices
  1. Enhanced best practices for outdoor storage of hydrogen cylinders.
  2. Added more information on hydrogen properties in collaboration with NASA.
  3. Updated “Hydride Storage and Handling” to cover risks related to large-scale experiments in collaboration with SNL.
- H2 Incident Reporting and Lessons Learned
  1. Currently 195 incidents recorded in the database.
  2. Created new “Lessons Learned Corner” to analyze hydrogen safety themes illustrated by database content.

Progress

U.S. DEPARTMENT OF ENERGY

Sensor Testing



Packaged LANL/LLNL Mixed Potential Zirconia-based H_2 Sensor for Independent Testing

Objective:

- Develop a low cost, low power, durable and reliable hydrogen safety sensor for vehicle and infrastructure applications.
- Demonstration of working technology through applications of commercial and reproducible manufacturing methods and rigorous life testing results guided by materials selection, sensor design and electrochemical R&D investigation.
- Disseminate packaged prototypes to DOE laboratories and commercial parties interested in testing and fielding advanced commercial prototypes while transferring technology to industry.

Benefits and Challenges:

- Low cost sensors for hydrogen leakage needed for vehicles and pipelines.
- Potential liability issues and lack of insurability affecting the commercialization of hydrogen technologies.
- Variation in standard practice of hydrogen safety assessments.

Approach:

- Focus on the long-term testing, packaging and manufacturing protocol for the commercialization of hydrogen sensor technology.
- Evaluate alternative measurement and electrode processing methods to further improve sensor stability.
- Coordination: LANL, LLNL and ElectroScience Laboratories with BJR Sensors.

Key Deliverables and Milestones:

- Go for mode of operation and fabrication processes with critical evaluation of mass manufacturing potential.
- Multiple devices fabricated and packaged for 1st round of testing/independent validation at NREL facility.
- Application of BJR Passive Duel Technology (PDT) shows promise with near 100% rejection of cross-interference gas species tested.

Accomplishments

- Developed miniaturized, low power and robust hydrogen sensor prototype conducive to commercialization.
- Developed stable sensor response over time.
- Multiple devices fabricated and packaged showing high-degree of reproducibility device-to-device.
- Incorporation of miniature Resistance Temperature Detectors (RTD) in sensor platform to provide continuous T feedback and control point.
- Developed methods for rejection of cross-sensitivity to common interference gases tested.
- Completed long-term testing of improved electrode devices at LANL and at LLNL on separate devices.
- Completed 1st round of testing packaged H_2 safety sensors at NREL.

Progress

Fuel Quality

Hydrogen Fuel Quality Test Apparatus

Objective:

Determine levels of constituents for the development of an ANSI and international standard for hydrogen fuel quality (ISO TC197 WG12).

Benefits and Challenges:

- Remaining Tests for Fuel Specifications:
  1. Testing critical constituents at reduced levels
  2. Reduce anode loading: .05 mg Pt/cm^2 (DOE 2015 target)
  3. Short term tests: typical vehicle operation (5-10 hours)
  4. Start/stop Fuel Cell operation
  5. Aged studies
- Critical Constituents:
  1. Lower Pt loadings may increase performance losses via surface poisoning and/or within the catalyst layer
  2. Short-term tests may help reduce the build-up of adsorbates and/or cation uptake
  3. Shut down may be to some extent be helpful as a recovering strategy (introduction of air to remove excess hydrogen)
  4. Aged fuel cells may inhibit particle growth and/or ionomer loss (similar to lowering Pt loading)

Approach:

- Help determine levels of constituents and test these critical constituents (NH_3, CO and H_2S) at various conditions (loadings, relative humidity and concentrations) and present data at ISO WG 12 meetings.
- Coordination: University of Hawaii/HNEI, University of Connecticut, University of South Carolina, Clemson University, SRNL, NIST, NREL and ANL

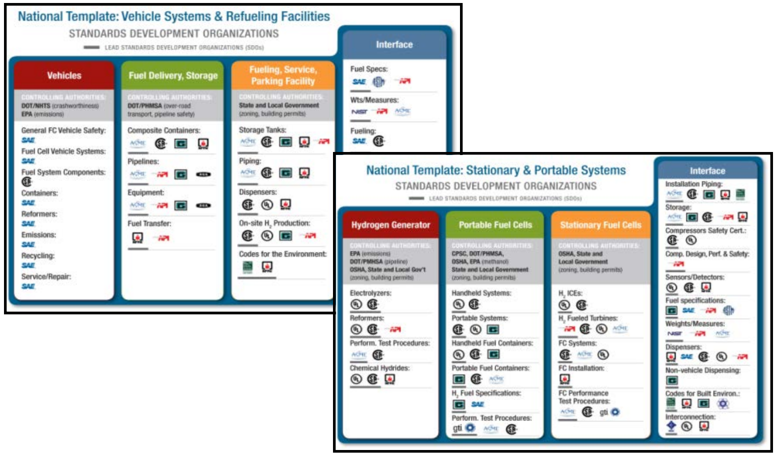
Key Deliverables and Milestones:

- Complete testing of critical constituents at various conditions (loadings, relative humidity and concentrations).

Accomplishments

- H_2S Gore Standard MEA: Slower poisoning onset, but when accumulation occurs these results differ.
- Project produced excellent experimental and modeling results that were adopted by the international community.
- Significant progress on establishing cross contamination effects.
- Data presented at ISO WG 12 Meetings in Berlin, Germany; Seoul, Korea; and San Francisco, CA.

National Template



National Template: Vehicle Systems & Refueling Facilities

STANDARDS DEVELOPMENT ORGANIZATIONS

LEAD STANDARDS DEVELOPMENT ORGANIZATIONS (SDOs)

Vehicles

CONTROLLING AUTHORITIES:
DOT/NHTS (crashworthiness)
EPA (emissions)

General FC Vehicle Safety:
Fuel Cell Vehicle Systems:
Fuel System Components:
Containers:
Reformers:
Emissions:
Recycling:
Service/Repair:

Fuel Delivery, Storage

CONTROLLING AUTHORITIES:
DOT/PHMSA (over-road transport, pipeline safety)

Composite Containers:
Pipelines:
Equipment:
Fuel Transfer:

Fueling, Service, Parking Facility

CONTROLLING AUTHORITIES:
State and Local Government (zoning, building permits)

Storage Tanks:
Piping:
Dispensers:
On-site H_2 Production:
Codes for the Environment:

Interface

Fuel Specs:
Wts/Measures:
Fueling:

National Template: Stationary & Portable Systems

STANDARDS DEVELOPMENT ORGANIZATIONS

LEAD STANDARDS DEVELOPMENT ORGANIZATIONS (SDOs)

Hydrogen Generator

CONTROLLING AUTHORITIES:
EPA (emissions)
DOT/PMHSA (pipeline)
OSHA, State and Local Gov't (zoning, building permits)

Electrolyzers:
Reformers:
Perform. Test Procedures:
Chemical Hydrides:

Portable Fuel Cells

CONTROLLING AUTHORITIES:
CPSC, DOT/PHMSA,
OSHA, EPA (methanol)
State and Local Government (zoning, building permits)

Handheld Systems:
Portable Systems:
Handheld Fuel Containers:
Portable Fuel Containers:
H_2 Fuel Specifications:
Perform. Test Procedures:

Stationary Fuel Cells

CONTROLLING AUTHORITIES:
OSHA, State and Local Government (zoning, building permits)

H_2 ICEs:
H_2 Fueled Turbines:
FC Systems:
FC Installation:
FC Performance Test Procedures:

Interface

Installation Piping:
Storage:
Compressors Safety Cert.:
Comp. Design, Perf. & Safety:
Sensors/Detectors:
Fuel specifications:
Weights/Measures:
Dispensers:
Non-vehicle Dispensing:
Codes for Built Environ.:
Interconnection:

National Template Web site

Objective:

- Conduct R&D needed to establish sound technical requirements for renewable energy codes and standards with a major emphasis on hydrogen and fuel cell technologies.
- Support code development for the safe use of renewable energy in commercial, residential and transportation applications with a major emphasis on emerging fuel cell technologies.
- Advance renewable energy safety, code development and market transformation issues by collaboration with appropriate stakeholders.
- Facilitate the safe deployment of renewable energy technologies.

Benefits and Challenges:

- Consensus: achieving national agenda on codes and standards.
- Representation: government and industry support and DOE limited role.
- Technology Readiness: jurisdictional issues related to available codes and existing setback distances.

Approach:

- Support codes and standards coordination and development including coordinating involvement in technical committees and coordinating committees.
- Project Timeline: October 2002 – Continuing
- Coordination: California Fuel Cell Partnership (CaFCP), California Air Resource Board (CARB), FCHEA, SNL, LANL, ORNL, ANL, PNNL, NASA, NIST, JRC, SAE, NFPA, CSA America, ICC, CGA, ISO and IEC

Key Deliverables and Milestones:

- Publish Stationary Fuel Cell Application Codes and Standards Gap Analysis
- Direct support of several codes and standards development projects:
  1. NFPA2 Hydrogen Technologies Code
  2. ISO 14687-2 Hydrogen Fuel quality standard
  3. SAE Standards
  4. CSA Component standards

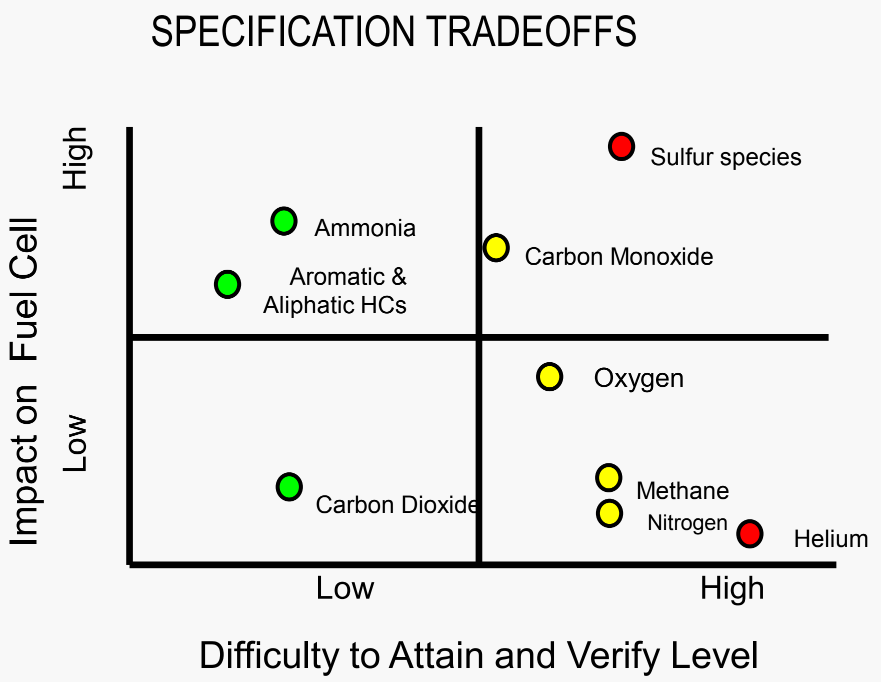
Accomplishments:

- Published Stationary Fuel Cell Application Codes and Standards Gap Analysis (October 2010)
- Direct participation on the following codes and standards committees:
  1. NFPA2 Hydrogen Technologies Code issued December 14, 2010
  2. ISO TS14687-2 Hydrogen Fuel Quality
  3. SAE J2579 Onboard Hydrogen Storage
  4. SAE J2578 General Fuel Cell Vehicle Safety
  5. SAE Fuel Cell Technical Committee
  6. CSA America H4
  7. ISO 20100 Hydrogen Fueling Stations
  8. UL2267 Fuel Cell Powered Forklifts

Progress

- Technical Specification (TS) published and harmonized with SAE J2719, Committee Draft (CD) prepared
- Draft International Standard (DIS) to be submitted to ISO TC197 Dec 2010
- Unified testing underway at LANL, HNEI, USC, Clemson-SRNL, UConn for critical contaminants
- Collaborative testing underway in Japan (JARI) and France (CEA-Liten)
- Developing standardized sampling and analytical methodologies with ASTM
- Applied ANL fuel cell stack and PSA models to support testing and to address fuel quality-fuel cost tradeoffs
- Coordinated overall approach and testing with Fuel Cell, Delivery, and Storage Tech Teams

Fuel Quality - ISO DIS 14687-2 Hydrogen Fuel Product Specification

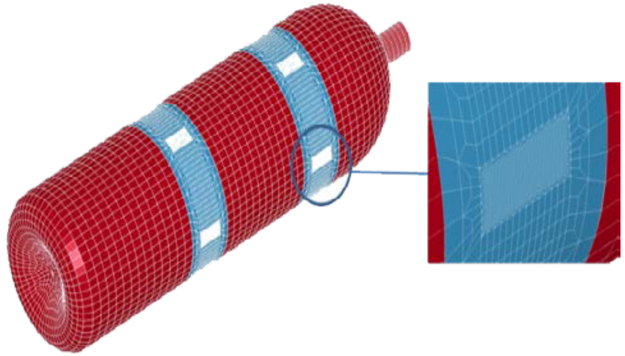


Source: Shell Hydrogen

Progress

U.S. DEPARTMENT OF ENERGY

Tank Cycle-Life Testing



Structural Engineering Analysis of Cylinder

Objective

- Provide technical basis for the development of standards defining the use of steel (type 1) storage tanks with existing defects

1. Engineering Analysis Method: validate fracture mechanics-based design approach in ASME BPVC Sec VIII, Div 3, Article KD-10
2. Performance Evaluation Method: provide data to help determine if time for crack initiation can be reliably credited in design qualification process
3. Quantify failure characteristics

- Participate directly in standards development such as ASME, CSA HPIT1 working group and SAE J2579

Benefits and Challenges

- Program provides the technical basis addressing this need within the scope of CSA HPIT1.
- Hydrogen accelerates fatigue crack growth of existing defects including crack growth under cyclic stress and critical crack propagation.
- Standards for steel hydrogen tanks that experience a large number of cycles is currently missing (CSA HPIT1).

Approach

- Perform testing and analysis of hydrogen accelerated fatigue crack growth of existing defects to provide basis for standards development activities
- Project Timeline: January 2010 – May 2011 (75% complete)
- Coordination: CSA HPIT1 working group, FCHEA Fork Lift Task Force, Tank Manufactures, Norris Cylinder, Nuvera and Plug Power

Key Deliverables and Milestones

- Complete cycling of as-manufactured tanks and tanks with engineered flaws until failure
- Complete benchmark fatigue crack growth testing of 3 heats of 4130X
- Quantify number of cycles for initiation and growth as well as size and distribution of engineered and “natural” defects
- Validate structural engineering tools and existing design methodology (in particular ASME VIII.3.KD-10 and leak-before-burst criteria)
- Communicate results to CSA HPIT1 working group and SAE J2579

Accomplishments

- As-manufactured tanks have experienced 25,000 cycles as of Feb 2011
- Fatigue crack growth rates have been measured for each tank material
- Test matrix defined with input from partners (HPIT1 working group)
- Infrastructure has been developed for accelerated qualification test method development