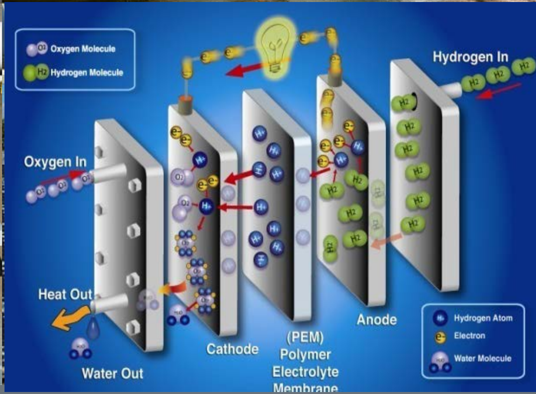
Fuel Cell Technologies Office: Safety, Codes and Standards Overview and Status

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



6th International Conference on Hydrogen Safety: Safety Session

Yokohama, Japan

October 19, 2015

Will James

Project Manager

Safety, Codes and Standards Program

Fuel Cell Technologies Office

U.S. Department of Energy

SCS Program Goal and Objectives

Codes & Standards Objectives:

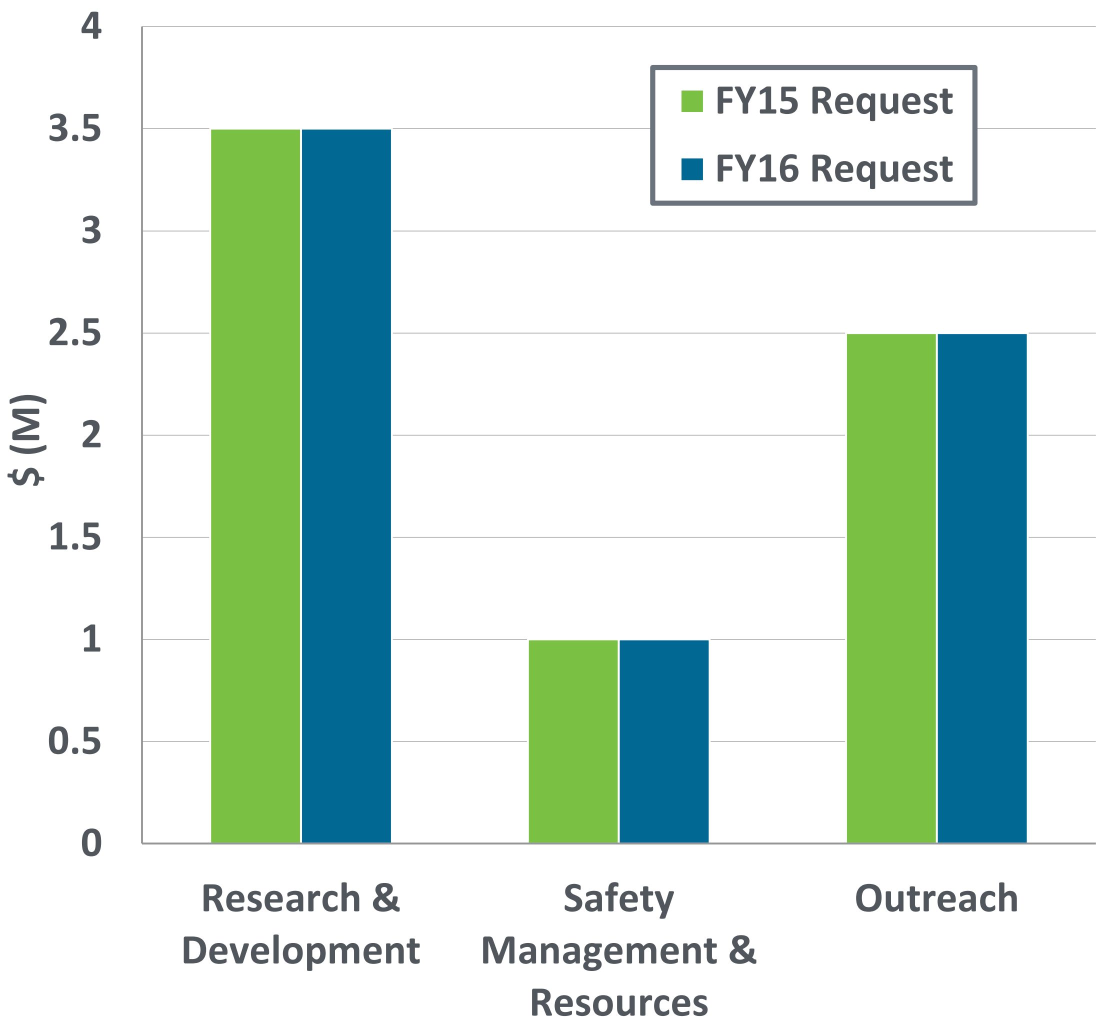
- Support and facilitate development and promulgation of essential codes and standards to enable widespread deployment and market entry of hydrogen and fuel cell technologies and completion of all essential domestic and international regulations, codes and standards (RCS)
- Conduct R&D to provide critical data and information needed to define requirements in developing codes and standards.

Hydrogen Safety Objectives:

- 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.

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

SCS Budget



FY 2016 Request = $7M

FY 2015 Appropriation = $7M

Emphasis

- **R&D Activities:** H_2 Behavior, Risk Assessment/Mitigation, Materials Compatibility, H_2 Fuel Quality, Metering, Sensors, Component Testing
- **Safety Management & Resources:** Hydrogen Safety Panel, Databases, and Training Props
- **Outreach:** Codes & Standards and Permitting, Continuous Codes and Standards Improvement, Resource Dissemination

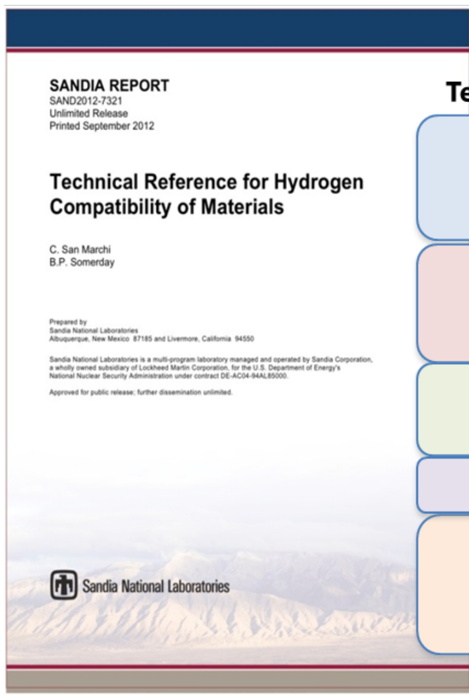
FY 2016 request maintains stable funding and allows for continued emphasis on critical RCS and safety

Thinking Back……

Were are the FCEV and hydrogen infrastructure codes and standards?

SNL Technical Reference helps Launch SCS

- Information placed on OpenEI website: http://en.openei.org/wiki/Gateway:Hydrogen
  - Updated full public report on Technical Reference for Hydrogen Compatibility of Materials (SAND2012-7321), 292 pages
  - Datasets for fatigue crack growth of materials in gaseous hydrogen


SANDIA REPORT
SAND2012-7321
Unlimited Release
Printed September 2012

Technical Reference for Hydrogen Compatibility of Materials

C. San Marchi
B.P. Somerday

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Approved for public release; further dissemination unlimited.

Sandia National Laboratories

Technical Reference	Technical Database
1100 Carbon steels └ 1100: C-Mn alloys	1100 Carbon steels ├ CIA85: tension, fracture, fatigue ├ SAN10: fracture, fatigue └ SAN11: fracture fatigue
1200 Low-alloy steels ├ 1211: Cr-Mo alloys └ 1222: Ni-Cr-Mo alloys	1200 Low-alloy steels └ NIB10: fracture, fatigue
1400-1800 High-alloy steels └ 1401: 9Ni-4Co	1400-1800 High-alloy steels
2000 Austenitic steels	2000 Austenitic steels
3000 Aluminum alloys ├ 3101: Pure aluminum ├ 3210: 2xxx-series alloys └ 3230: 7xxx-series alloys	3000 Aluminum alloys └ SAN11: fracture, fatigue

Established close to 1998 with the development of the Technical Reference at Sandia National Laboratories

R&D Support for RCS Development

R&D Roadmap

Multi-year Program Plan

Hydrogen Behavior

Unintended releases (modeling and validation)

Dispersion, diffusion, entrainment

Ignition, flammability (mechanisms, propagation)

Test Methods, Component/System Performance

Critical materials, components, systems

Test methods, protocols, validation

Certification processes, system qualification

Data, Analysis, Implementation

Handbooks, data resources

Risk assessment

Mitigation

Science and Technology Foundation:

Regulations, codes and standards (RCS) based on data and scientific understanding.

RCS Development and Harmonization

Support completion of essential codes and standards

Facilitate uniform implementation of requirements in US

Harmonize requirements in domestic and international standards

Support and facilitate completion of Phase 1 GTR H2 vehicle systems

Education Outreach, Training

Support Hydrogen Safety Panel and lessons learned database

Conduct hands-on training and education for first responders

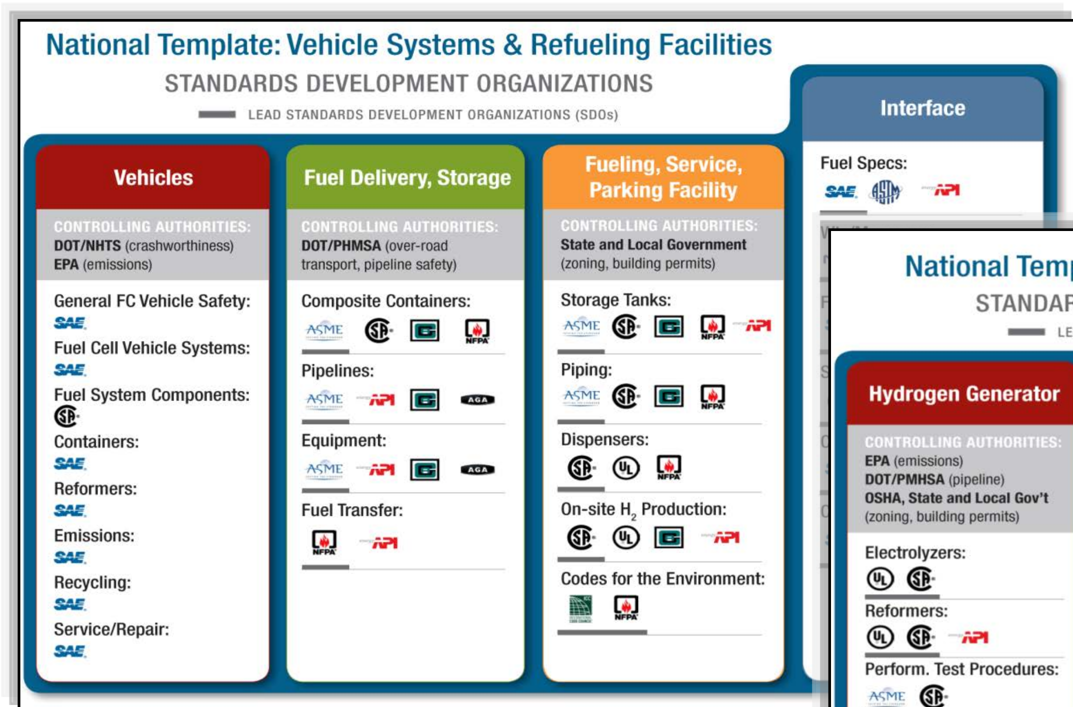
Commercialization Decision

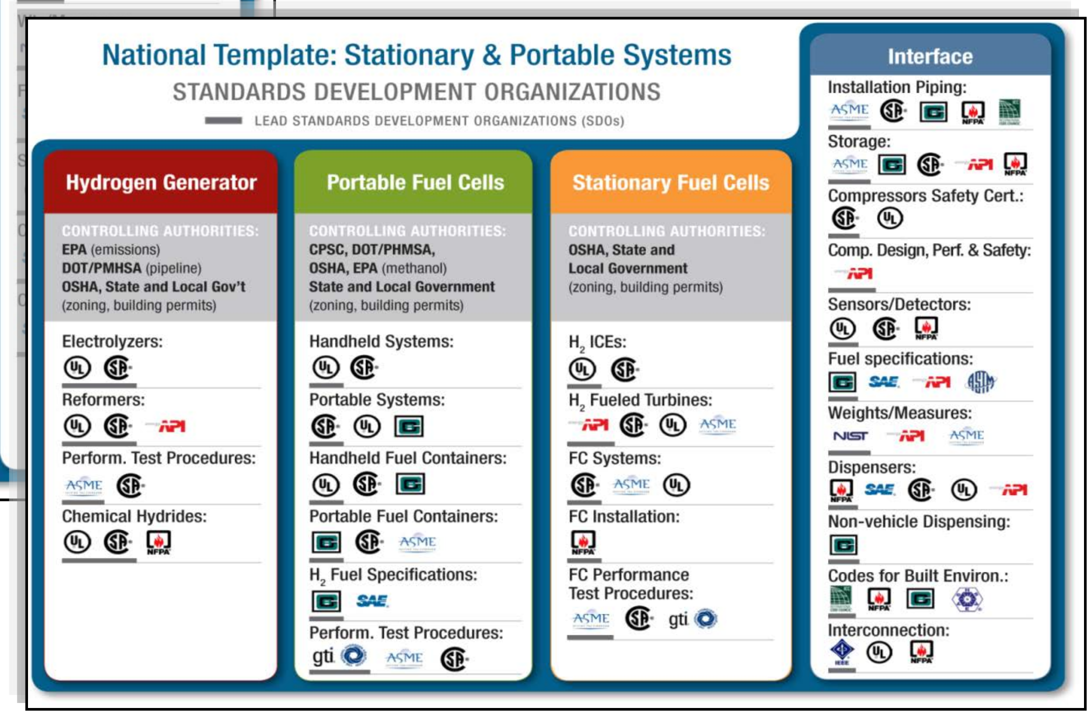
Enabling the growth of early markets by establishing essential regulations, codes and standards (RCS) validated by scientific research and testing and developed through consensus of all major stakeholders.

Establish regulations, codes and standards needed to enable full market deployment of hydrogen and fuel cell technologies

Lack of Hydrogen and Fuel Cell Standards

National Codes and Standards Template





Latest version available online at:
http://energy.gov/eere/fuelcells/downloads/national-template-hydrogen-vehicle-and-infrastructure-codes-and-standards

National template developed in 2002 to delineate and coordinate critical roles of standards and model code development organizations

Timeline of Safety and Training Resources

2002 — 2002 | 2004 | 2006 | 2008 | 2010 | 2012 | 2014 — 2015

- 2002: **CaFCP Developed an ER Education Program**
- 2006: **Online Awareness Level Training**
- 2008: **Operations Level Class and Props Available**
- 2014: **Release of the National Hydrogen and Fuel Cells ER Training Resource**

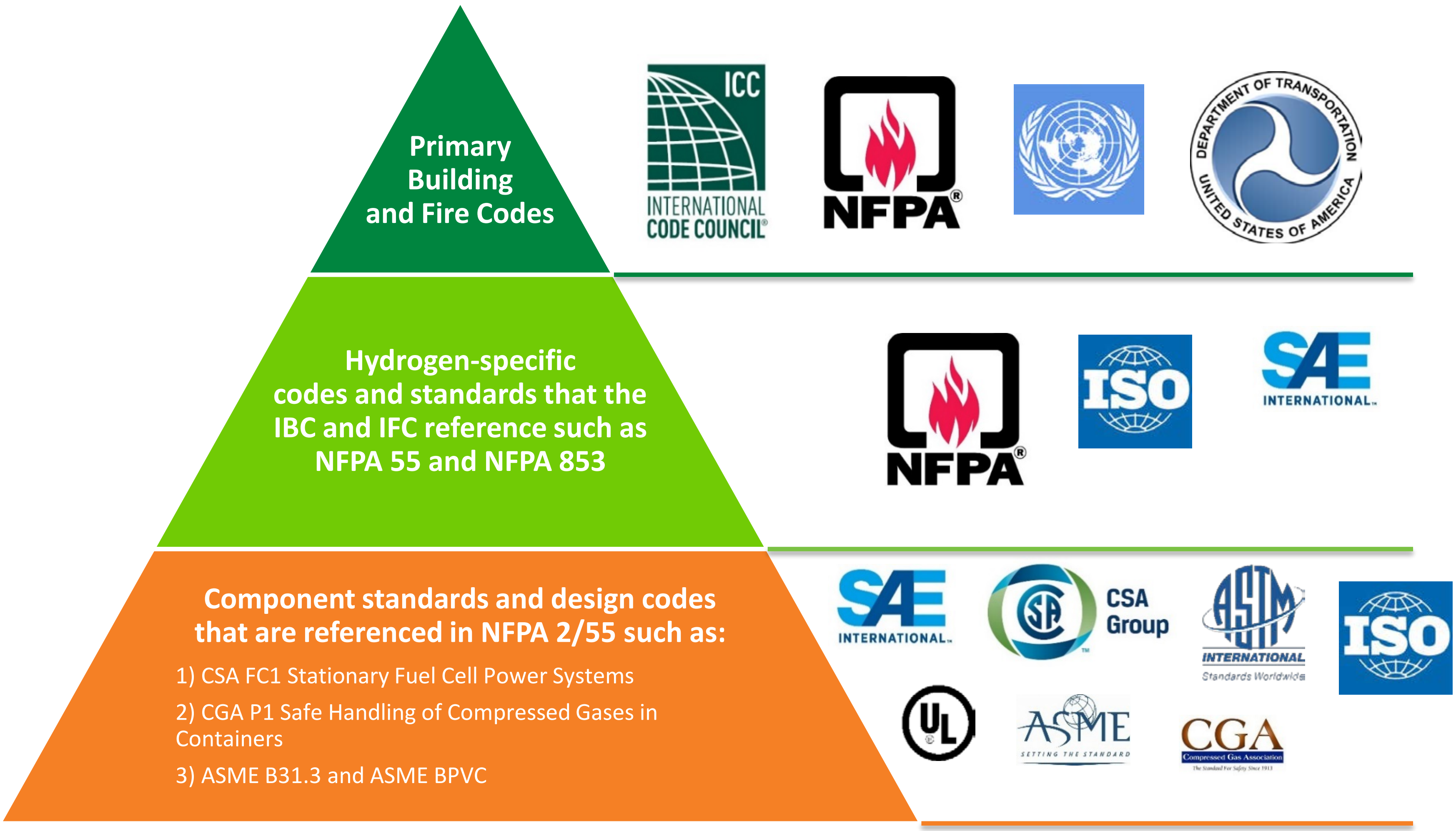
CaFCP training has reached over **7,000** first responders

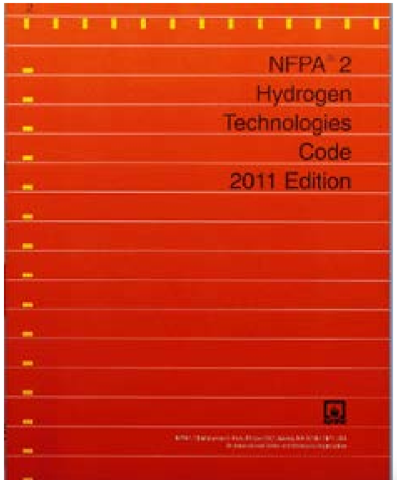
Over **32,000** visits for the online resource

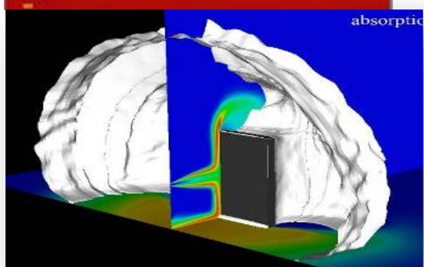
Operations level class has been attended by over **1,100** first responders

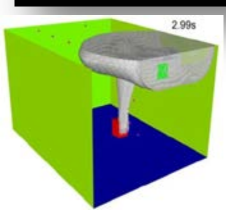
Online and in-person code official and first-responder training, with over 35,000 interactions, prepares communities for FCEVs

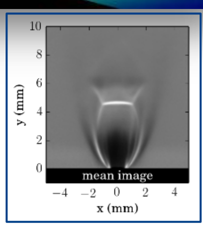
Building the Hierarchy of Regulations, Codes & Standards











	NFPA 55 (2005)	NFPA 2 (2011)
	GH2 - ft (m)	*GH2 - ft (m)*
Lot lines	0 (0)	**24 (7.3)**
Building openings or air intakes	**50 (15)**	**24 (7.3)**
Ignition sources	0 (0)	24 (7.3)
Exposed persons other than those servicing the system	nd	13 (4.0)
Places of public assembly	**50 (15)**	nd
Parked cars	15 (4.6)	13 (4.0)
Public sidewalks and parked cars	15 (4.6)	nd
Un-openable openings in building and structures	nd	10 (3.0)
Not above any part of the system	10 (3.0)	nd
Above any part of the system	25 (7.6)	nd
Overhead utilities	nd	10 (3.0)
Distance to overhead electric wire of electric trolley/train/bus line	50 (15)	nd
Required area for separation distance based on table alone	**3780 ft^2 (351 m^2)**	**5304 ft^2 (493 m^2)**
Required area for sample installations*	**12480 ft^2 (1159 m^2)**	**5304 ft^2 (493 m^2)**

*Data from report: http://energy.sandia.gov/wp-content/gallery/uploads/SAND_2014-3416-SCS-Metrics-Development_distribution.pdf

- Applies to the production, storage, transfer, and use of hydrogen in both gaseous and liquid forms.

NFPA 2 Hydrogen Technologies Code was published in 2011, which utilized a science-based approach

Harmonization of Fuel Quality

Table C.1: Hydrogen Fuel Quality Specification				
Constituent	Chemical Formula	Limits [e]	Laboratory Test Methods to Consider and Under Development [f]	Minimum Analytical Detection Limit
Hydrogen fuel index	H_2	>99.97%		
Total allowable non-hydrogen, non-helium, non-particulate constituent		100 µmol/mol		
Acceptable limit of each individual constituent				
Water [a]	H_2O	5 µmol/mol	ASTM D7653-10, ASTM D7649-10	0.12 µmol/mol
Total hydrocarbons [b] (C_1 basis)		2 µmol/mol	ASTM D7675-11	0.1 µmol/mol
Oxygen	O_2	5 µmol/mol	ASTM D7649-10	1 µmol/mol
Helium	He	300 µmol/mol	ASTM D1945-03	100 µmol/mol
Nitrogen, Argon	N_2, Ar	100 µmol/mol	ASTM D7649-10	5 µmol/mol
Carbon dioxide	CO_2	2 µmol/mol	ASTM D7649-10, ASTM D7653-10	0.1 µmol/mol
Carbon monoxide	CO	0.2 µmol/mol	ASTM D7653-10	0.01 µmol/mol
Total sulfur [c]		0.004 µmol/mol	ASTM D7652-11	0.00002 µmol/mol
Formaldehyde	HCHO	0.01 µmol/mol	ASTM D7653-10	0.01 µmol/mol
Formic acid	HCOOH	0.2 µmol/mol	ASTM D7550-09 , ASTM D7653-10	0.02 µmol/mol
Ammonia	NH_3	0.1 µmol/mol	ASTM D7653-10	0.02 µmol/mol
Total halogenates [d]		0.05 µmol/mol	ASTM WK23815, WK34574	0.01 µmol/mol
Particulate Concentration		1 mg/kg	ASTM D7650-10, ASTM D7651-10	0.005 mg/kg

- Fuel quality specification references at the nozzle (interface between vehicle and station)
- Harmonization of SAE 2719 (Sept 2011) and ISO 14687-2 (Dec 2012)
- Committee participation included OEMs, IGCs, Oil Companies, States, FC integrators, etc.
- Testing only occurs in the event of a dispute

Harmonization of the Fuel Quality Specification between SAE and ISO, which was completed in Dec 2012, allows for consistency in the fuel delivered to the fuel cell.

Global Technical Regulation

Objective

Develop performance-based and harmonized international regulations, codes and standards (RCS) critical to fair and open competition in worldwide markets for hydrogen and fuel cell vehicles.

Benefits and Challenges

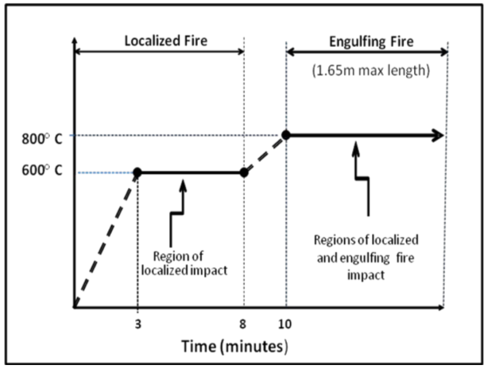
- Fair and open competition in worldwide markets for hydrogen and fuel cell vehicles.
- Ensure that U.S. (North American) interests and concerns are considered in the development of global RCS.

Approach

- Team with the Department of Transportation.
- Consistent high-level technical representation.
- Technical proposals and scientific data from the automobile industry incorporated into GTR.

Localized Fire Test Example

Preliminary Temperature Profile

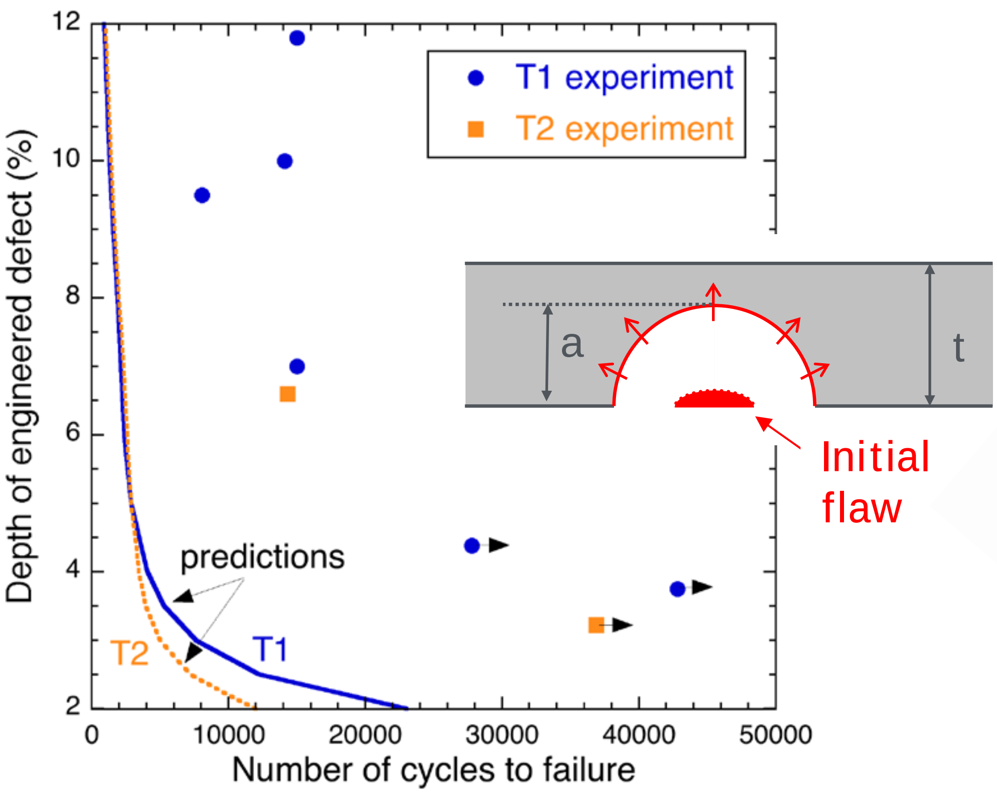


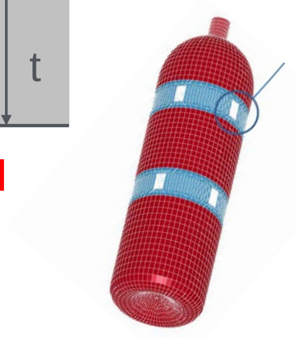
Accomplishments

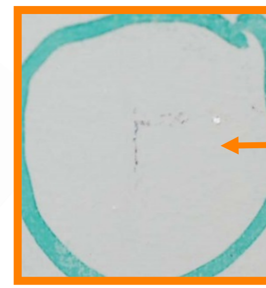
- Significant portions of SAE J2579 Technical Information Report for Fuel Systems in Fuel Cell and other Hydrogen Vehicles have been incorporated into the GTR.
- Technical experts provided extensive input to the GTR.

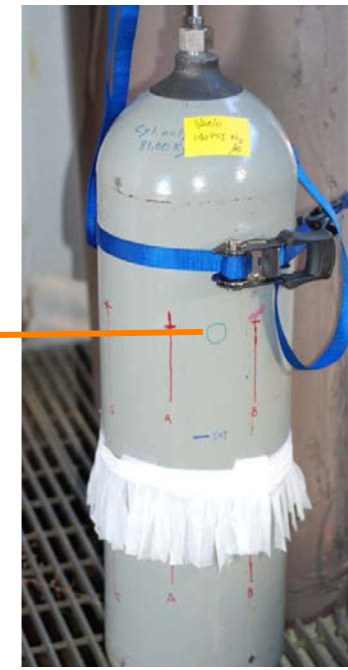
Final Approval of GTR occurred in June 2013. United States is currently leveraging the GTR to inform the Federal Motor Vehicle Safety Standard (FMVSS)

American Recovery and Reinvestment Act (ARRA)





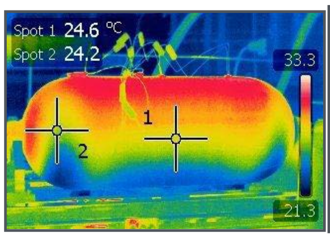


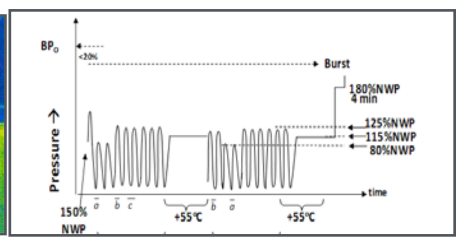


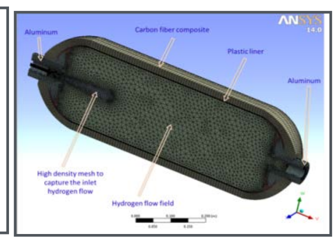
- **Fatigue life is conservative by factor >= 4; for small defects, safety factor approaches 10**
- **Enhanced safety and market growth is enabled through standards development**
- **Today, there are >5000 clean and efficient fuel cell forklifts in service (and growing!)**

Performed Hydraulic cycle tests (up to 25 MPa)

- Defined a unique test protocol patterned after SAE J2579, GTR, and EIHP rev12b.
- U.S. testing performed at the NASA WSTF w/real time 24/7 access to the acquisition computer
- China testing performed at the Institute of Process Equipment, Zhejiang University w/testing during a site visit from U.S.
- Lessons learned were implemented in a revised test method protocol for the 2nd tank





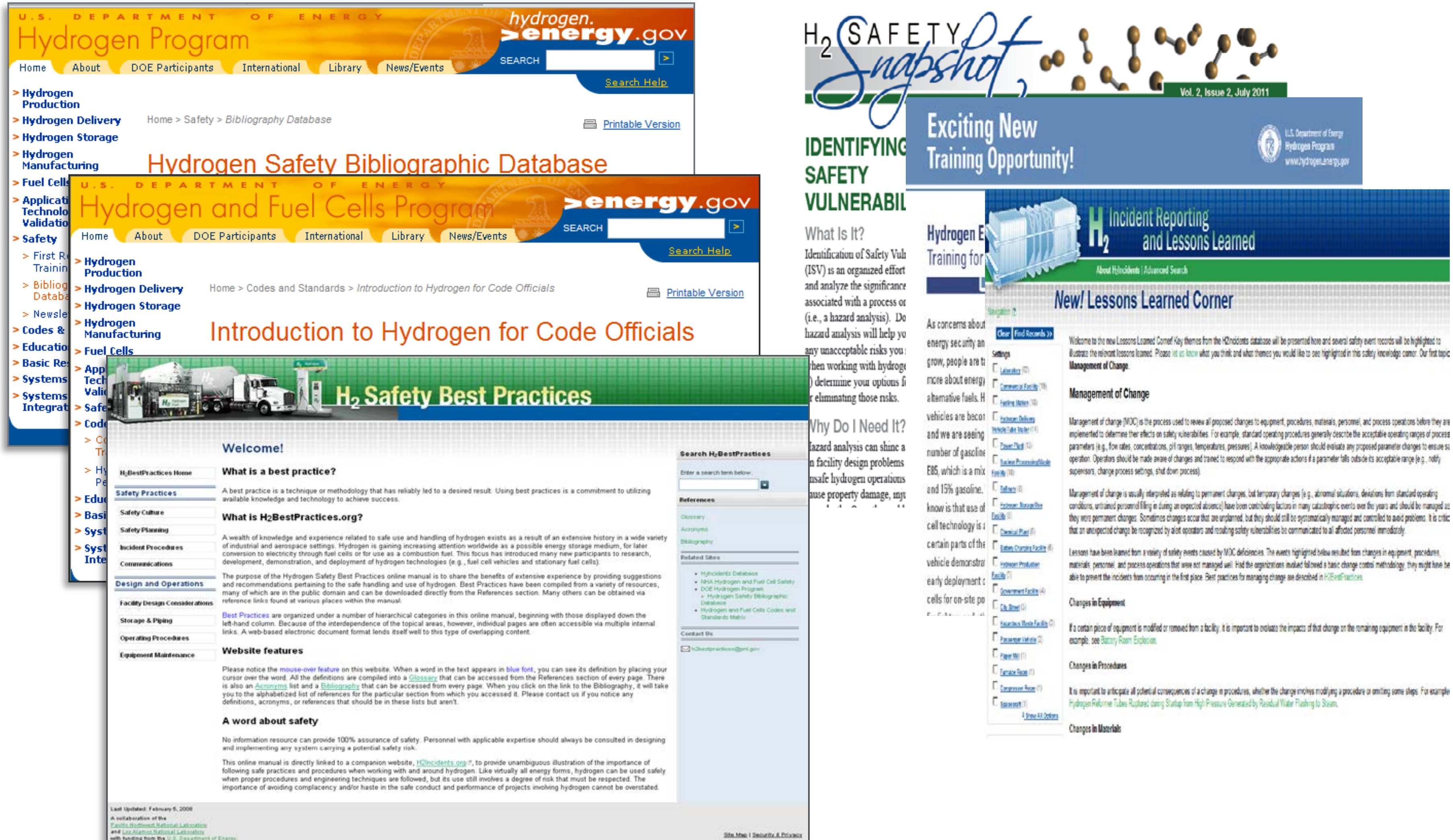


Hydraulic Phase RR on Type IV Tank completed under the IPHE RCSWG

Impact of SCS R&D on Codes and Standards

Regulation, Code or Standard	DOE Support	Status	Time Saved (resulting from DOE Support)
Global Technical Regulation (GTR) for fuel cell vehicles	Tank testing data; SAE standard, which provided basis for document; expert technical support from Dr. Sloane and Glenn Scheffler	Approved by UN GRSP WP 29 in June 2013	5 years
NFPA 2 Hydrogen Technologies Code and Integration into International Fire Code (IFC)	Extensive technical analysis to develop risk informed requirements for siting hydrogen storage systems; extensive logistical support including committee chair and consultant producing draft code document	Final document promulgated 2011; integrated into IFC 2013	3 years
SAE J2601 Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles	Performed validation testing for fueling algorithm in standard; provided logistical support for SAE Fuel Cell Technical Committee	Published 2014	3 years
SAE J2719 Development of a Hydrogen Quality Guideline for Fuel Cell Vehicles/ISO 14687 Hydrogen fuel – product specification – part 2: proton exchange membrane (PEM) fuel cell applications for road vehicles	Extensive test data, logistical support, and coordination of ISO/SAE standard development activities	Published 2012	5 years
ASME B31.12 Hydrogen Piping and Pipelines	Provided test data and logistical support	Final document 2008	3 years
ASME Article KD 10 Hydrogen Material Compatibility	Provided test data and analysis	Document issued 2008	5 years

Development of Safety Knowledge Tools



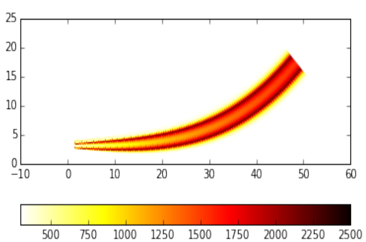
More than 212 Lessons Learned events in "H2Incidents.org" and about 750 entries in the Hydrogen Safety Bibliographic Database

Thinking Forward……

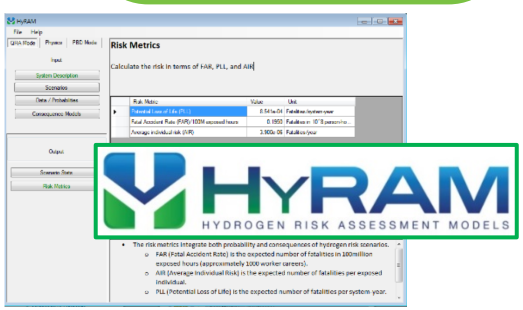
What's Next for SCS?

Cold Hydrogen Release Laboratory → **Hydrogen Risk Assessment Models (HyRAM)** → **Alternative Compliance Methods** → **Station Deployment**

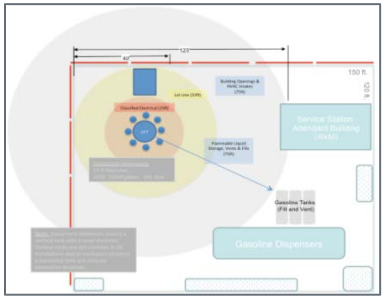
Cold Hydrogen Release Laboratory: Validate liquid H_2 (LH_2)models enable risk assessment tools. New cryo-temperature laboratory will bring a science-based approach to LH2 at the code committees.



Hydrogen Risk Assessment Models (HyRAM): Quantitative risk assessment (QRA) utilizes engineering models to produce risk metrics which enable performance-based design.



Alternative Compliance Methods: Performance-based design is a risk-enabled (via QRA), NFPA 2 - compliant option for station design.

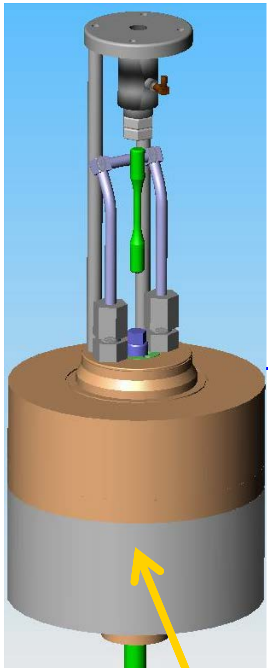


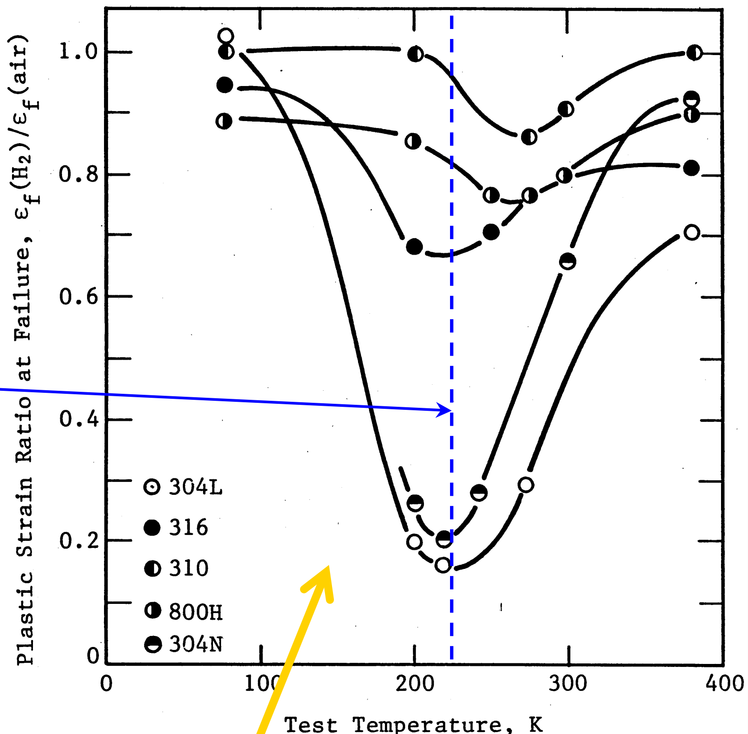
Station Deployment

At SNL, validated H_2 behavior models are incorporated into HyRam, enabling performance based compliance accelerating safe infrastructure deployment

Supporting Deployment Through R&D: H_2 Materials

Low-Temperature Testing of Materials in Hydrogen Atmosphere (SNL)





Low-temperature pressure vessel internal structure

Ductility of stainless steels in H2 gas normalized by ductility in air

Compatibility of Polymeric Materials used in Hydrogen Infrastructure (PNNL, SNL, ORNL)

- **Objective:** generate a foundational understanding of the unique effects associated with the ***combination of high pressure and H2*** on the integrity of polymer materials and generate the knowledge will be used to develop ***standardized test methods*** to enable science-based selection of materials for H2 service.
- Testing results will be published for dissemination in existing distribution platforms, such as H2Tools.org and the Technical Reference for H2 Compatibility of Materials.

Developing a knowledge base for behavior of materials in hydrogen to support a fault tolerant robust hydrogen refueling infrastructure

Overcoming Critical Barriers for HRS Deployment

Leveraging Expertise of National Labs: NREL & Sandia National Laboratories

H2FIRST In Support of H2USA and tasked to deliver:

Reference Station Design

- ✓ Report Delivered with Detailed Station Designs and Cost Estimates

Fuel Contaminant Detection

- ✓ Market Survey and Gap Analysis Complete

HySTEP Device

- ✓ Design Complete - Currently Under Construction

- H_2 Station Equipment Performance Device
- H_2First Inaugural Task
- HyStEP will help reduce time required to place H_2 stations in service

Upcoming Tasks:

- o Reference Station Design – Phase 2
  - – *Modular (delivered, on-site electrolysis)*
  - – *Conventional (on-site SMR, on-site electrolysis)*
- o Consolidation Scheme
- o Meter Benchmarking

DOE's H_2FIRST project supports H2USA goals to address infrastructure

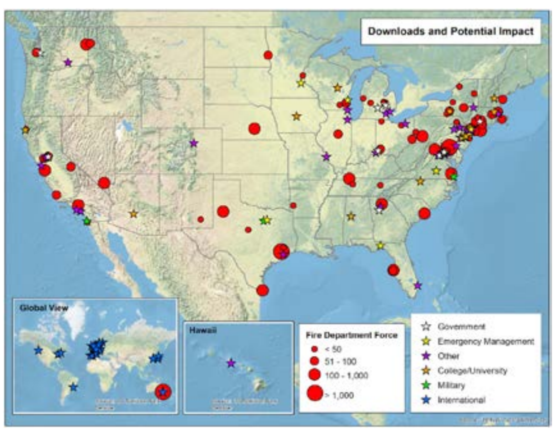
Unified Safety and Knowledge Resources

H2Tools.org, existing safety and knowledge resources are consolidated into a central location, with new functionality and content

Easier Acceptance of Hydrogen

First Responder Training (PNNL)

- Developing plans to transfer the online awareness training to the National Fire Academy, allowing:
  - a broader distribution of the materials,
  - better crediting of course completion/CEUs, and
  - a good long-term landing spot for the training.
- National Training Template adapts to existing training programs and easily updated



Code Official Training (NREL)

- Hydrogen station permitting video, designed to cover relevant topics for code officials, including:
  – Introduction
  – Why stations are needed
  – Background of Hydrogen Technologies
  – Codes and Standards for hydrogen stations
  – Maintenance
- Available soon, through DOE website and H2Tools.org

Developing a long-term strategy for hydrogen and fuel cell technology deployment involving publically available training!!

Why? FCEVs are on U.S. Roads Now!

Toyota Mirai FCV

1st commercially available FCEV for sale in the US

Toyota Mirai Fuel Cell Vehicle

Now Leasing…

Hyundai Tucson Fuel Cell SUV

In Auto Shows…

Honda Fuel Cell Electric Vehicle

OEMs are bringing fuel cells to showrooms and driveways

Hydrogen Refueling Stations





~50 Stations in California, 12 in the Northeast, > 200 Globally……..The stations are coming!!

Thank you

Will James - Team Lead
202-287-6223
charles.james@ee.doe.gov

hydrogenandfuelcells.energy.gov

Backup Materials

Safety, Codes & Standards Program Strategy

Research & Development

- Hydrogen Behavior
- Hydrogen Risk Assessment
- Materials Compatibility
- Fuel Quality
- Component Testing
- Sensors (both Safety and Contaminant Detection)

Codes & Standards Support and Implementation

- Domestic and International CDO and SDO participation and support
- Hydrogen Risk Assessment Models (HyRAM)
- Alternative Code Compliance Methods
- Continuous Codes and Standards Improvement
- Sensor Validation (industry engagement)

Outreach

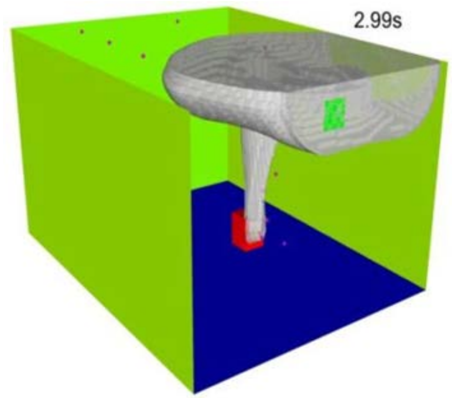
- Hydrogen Safety Panel
- Codes Official Training
- First Responders Training
- State Engagement and Support (e.g. – California and 8 State MOU)
- International Collaboration (e.g. – IPHE RCSWG, IA-HySAFE)
- Resource Development and Dissemination (training prop, H2Tools.org)

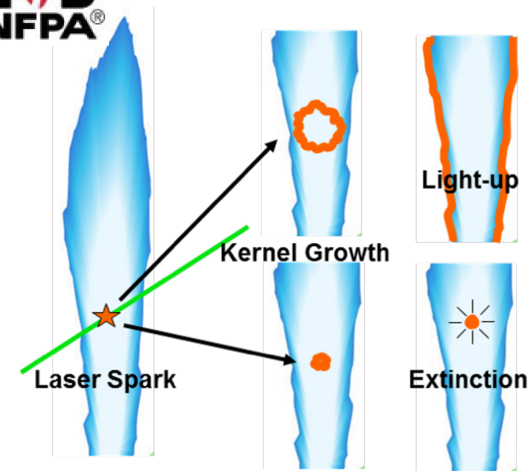
An integrated approach to safety, codes and standards: research and development informs codes and standards implementation efforts, which support outreach efforts

Accelerating Deployments with Quantitative Risk Assessments

Goal

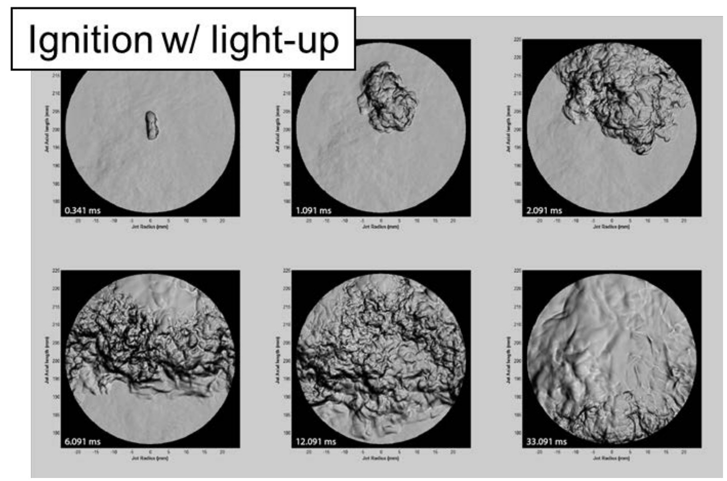
Facilitate the safe use of hydrogen and fuel cell technologies by understanding and mitigating risk





Demonstrated Impact

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



ANSI Code Revision Process

Process Segment	Time Required
Step 1 Input Stage- public input accepted as well input from other committees to develop first draft	49 Weeks
Step 2 Comment Stage- public comments on first draft accepted and acted on by committee	42 weeks
Step 3 Association Meeting- association member ship votes on document and any appeals at annual meeting	5 weeks
Step 4 Council Appeals and Issuance of Document- council acts on any appeals and issues final document or delays issuance based on the nature of the appeal	4 weeks
Step 5 Document publication- document is published after final action by the Council	5-16 weeks (approximately depending on complexity of document)
Total Time	*Approximately 2 years*

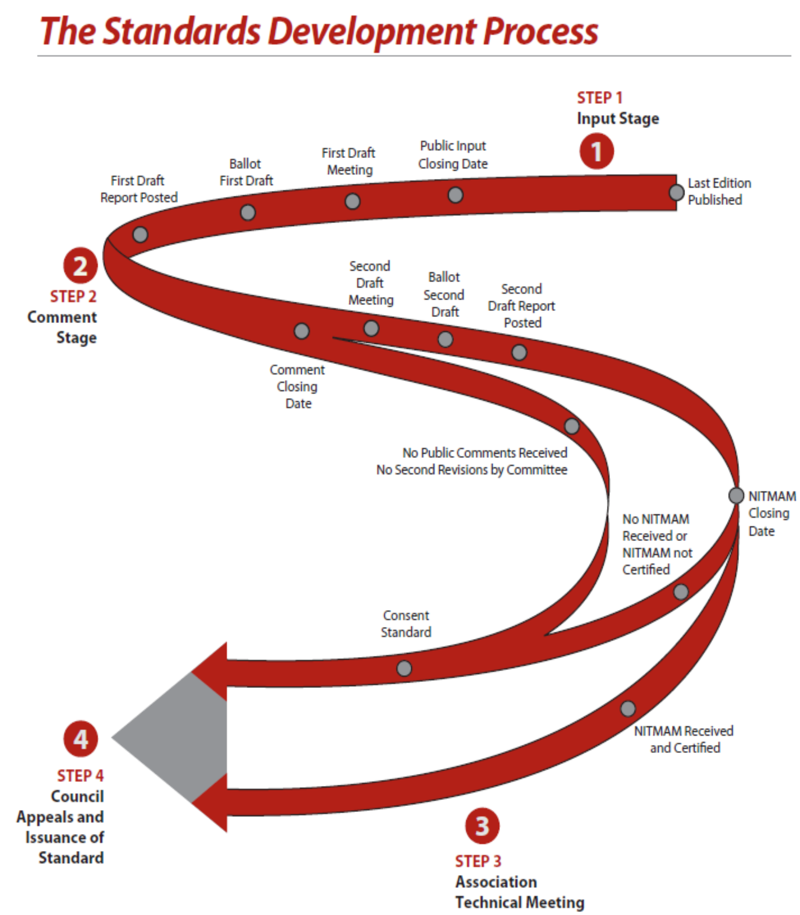
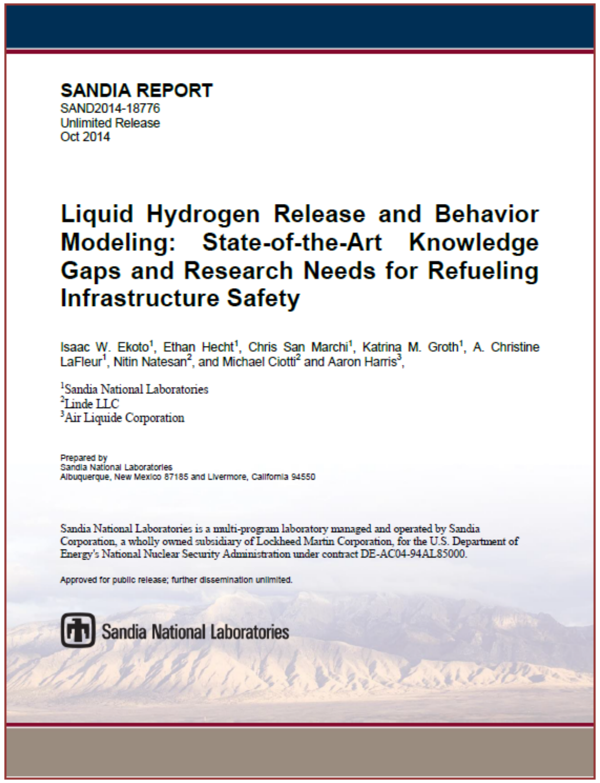


Image from NFPA

Current R&D Gaps

Critical gaps in R&D have been identified and must be "closed" to decrease separation distances and further the deployment of LH2 stations

- **Model development and validation:** LH2-specific models critical for development of risk-mitigation strategies
  - Adapt existing network flow models to determine accurate boundary conditions for liquid release
  - Reduced-order modeling for multiphase jet and plume flows
  - Accurate understanding of the dynamics of surface impingement and pooling
  - Study of effectiveness of barrier walls for liquid releases
- **Test methodology:** Lack of test platforms with adequate control of release boundary conditions
- **Risk mitigation:** Widespread acceptance of risk-mitigation strategies will make viable a wider range of sites for LH2 stations



SANDIA REPORT
SAND2014-18776
Unlimited Release
Oct 2014

Liquid Hydrogen Release and Behavior Modeling: State-of-the-Art Knowledge Gaps and Research Needs for Refueling Infrastructure Safety

Isaac W. Ekoto[1], Ethan Hecht[1], Chris San Marchi[1], Katrina M. Groth[1], A. Christine LaFleur[1], Nitin Natesan[2], and Michael Ciotti[2] and Aaron Harris[3],

[1]Sandia National Laboratories
[2]Linde LLC
[3]Air Liquide Corporation

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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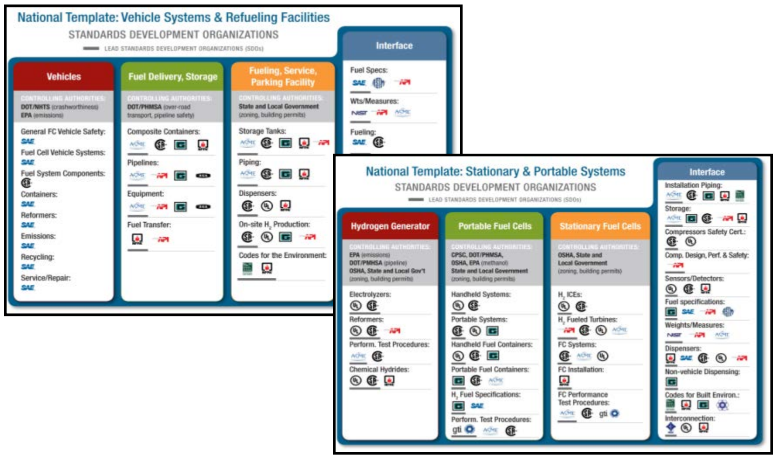
National Template



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

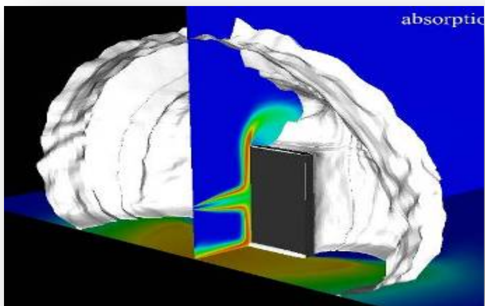
Accomplishments:

- 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

Safety, Codes & Standards R&D

Separation Distances

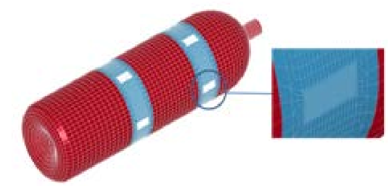
Provided technical data and incorporated a risk-informed approach that enabled NFPA2 to update bulk gas storage separation distances.



Example:
Barrier walls reduce separation distances – simulated position of allowable heat flux iso-surface for 3-minute employee exposure (2009 IFC).

Materials and Components Compatibility

- Demonstrated cycle-life of >50,000 refuelings of metals tanks for forklift applications
- Performed testing of forklift tank materials to enable design qualification
- Added two additional Nickel alloy chapters the Technical



Critical RCS Development

- NFPA 2 Hydrogen Technologies Code, *2011*
- Final Draft International Standard (FDIS) on Fuel Quality was published by ISO TC197 *Dec 2012*
- SAE J2719 was approved by the SAE Motor Vehicle Council as a Standard for Fuel Quality *Sept 2011*
- The Global Technical Regulation (GTR) for Hydrogen-fueled vehicles was approved by UN-ECE *June 2013*

International Round Robin

- Launched Phase 1 of international round robin on high-pressure composite overwrapped vessels.
- IPHE endorsed