National Codes and Standards Deployment and Outreach

Carl Rivkin
National Renewable Energy Laboratory
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DOE Hydrogen and Fuel Cells Program
2019 Annual Merit Review and Peer Evaluation Meeting

Project ID # SCS001

Overview

Timeline and Budget

- **Project start date:** October 1, 2002
- **Project end date*:** September 30, 2018
- **FY18 DOE funding: $330,000**
- **FY19 planned DOE funding: $430,000**
- **Total DOE funds received to date: $2,030,000**

*Project continuation and direction determined annually by DOE

Barriers

- G. Insufficient Technical Data to Revise Standards
- F. Enabling Markets Requires Consistent Regulations, Codes, and Standards (RCS)
- A. Limited Safety Data Access

Partners

- Regional fire departments and energy policy associations
- DOE national labs
- Industrial gas industry
- Component manufacturers
- Station operators
- Safety professionals
- Standards development organizations

Relevance

- Objectives: Projects further enable the safe deployment of hydrogen fuel cell technologies by informing the development of required codes with a particular focus on Hydrogen at Scale (H2@Scale)
- Project impact:
  - The Continuous Codes and Standards Improvement (CCSI) project supports technology deployment by enabling the integration of research into codes and standards to make more effective documents
  - The Codes and Standards Outreach and Training project supports technology deployment by informing the development of codes and standards information by project developers and code officials, making project permitting smoother and faster
  - The component failure project addresses fundamental safety issues in infrastructure deployment
  - These project impacts directly address DOE barriers to deployment (consistent, science-based codes and standards; having information readily available for users)
  - These projects have proven to be effective at furthering hydrogen technologies by integrating research into the code development process.

Integrating research into safety codes for safe infrastructure deployment

Approach

Strategy: Safe Deployment of Hydrogen Technologies

Collaborate with all interested parties
Includes industries, safety communities, research laboratories, standards development organizations, regional planning organizations

Leverage existing resources
For example, research projects that have a safety component that can be used to support development of safety codes

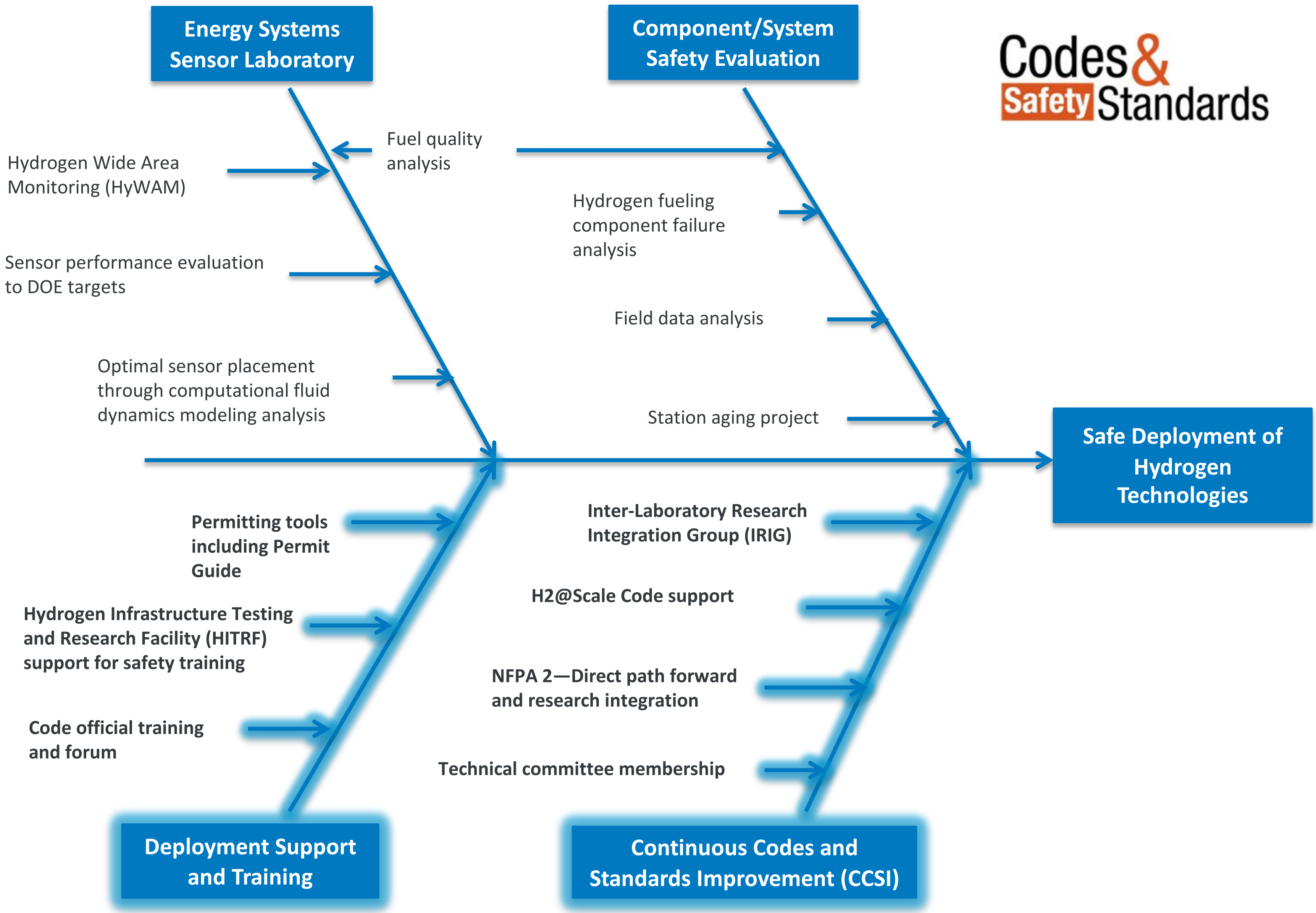
Develop safety requirements
Based on research and safety tools to inform safety code users

Fiscal Year 2019 Deliverables: Safety R&D Integration

- Identify H2@Scale system scenarios to consider in the development of a safety roadmap, in collaboration with the H2@Scale analysis team
- Create the field-failed investigation test plan and protocol for at least three leading safety and/or low-reliability components that could be delivered from station operators
- Lead the Permit Checklist Task Group to develop a draft Permit Checklist for NFPA 2 compliance for hydrogen fueling stations employing both gaseous and liquid hydrogen storage
- Report the failure investigation results for all received failed components using agreed-upon template

Collaborate with key stakeholders and leverage existing research to achieve safe deployment of hydrogen technologies

Approach: Integrated Safety Research

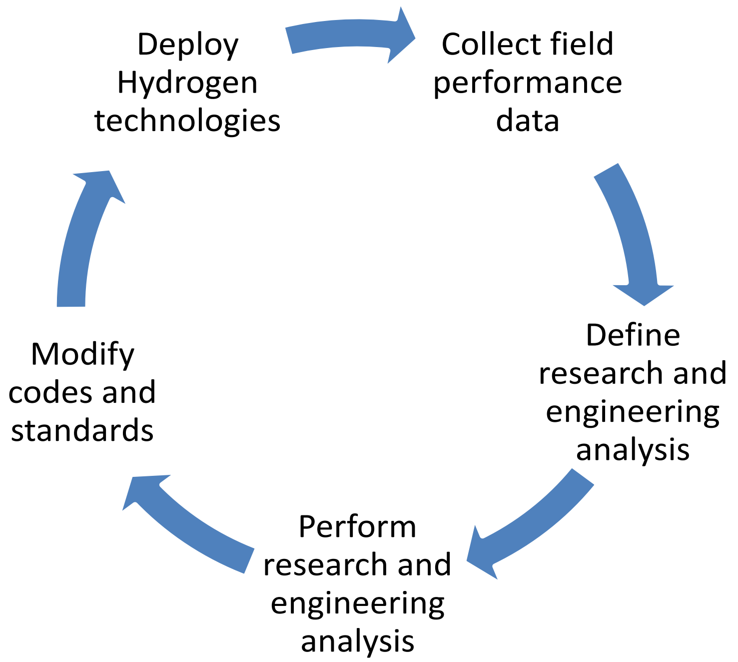


Approach: CCSI

CCSI Key Projects

- Through the Inter-Laboratory Research Integration Group (IRIG), utilize DOE research to develop defensible documented safety requirements
- Hydrogen fueling station component failure root-cause determination
- Integrate research into safety code infrastructure, such as hydrogen fueling infrastructure, hydrogen distribution systems, and existing vehicle infrastructure systems

CCSI Process

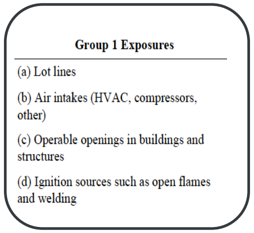


Impact: Codes that integrate current technology enable safer, faster deployment of hydrogen technologies

Approach: IRIG

DOE Office of Energy Efficiency and Renewable Energy

DOE-funded hydrogen technology and alternative fuel research projects conducted at DOE and other laboratories + Existing DOE supported research that could benefit public safety



Group 1 Exposures

(a) Lot lines

(b) Air intakes (HVAC, compressors, other)

(c) Operable openings in buildings and structures

(d) Ignition sources such as open flames and welding

Safety requirements that produce Increased public safety and reduced permitting and deployment costs

IRIG/CCSI process:
Research and testing needs defined from the code development committees/project deployment

Leveraging DOE research, particularly stranded R&D assets, can support major code proposals, such as setback distances, that will have beneficial impact on public safety

Accomplishments: IRIG Ranked Safety Projects and Defined Actions

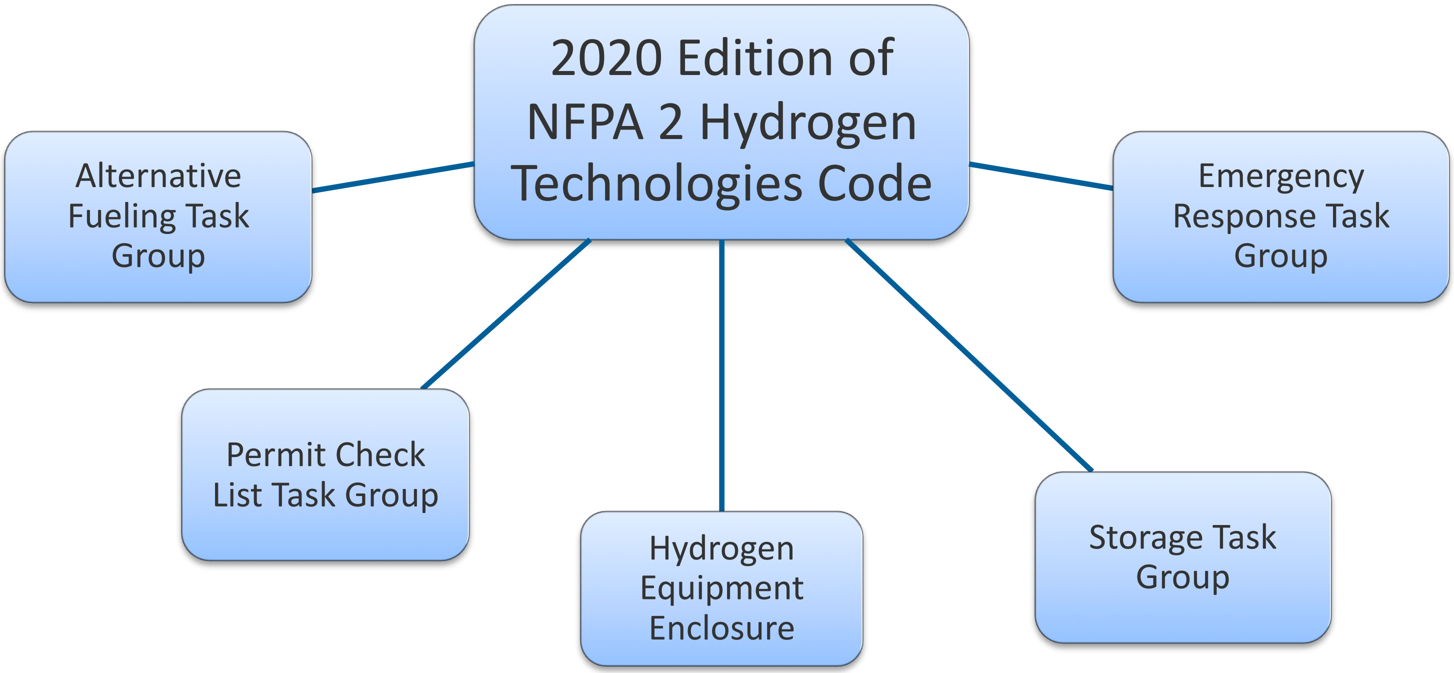
IRIG project safety ranking and actions

Project	Action
Project 1. Transportation issues including the distribution of hydrogen in existing pipeline systems and construction of new hydrogen pipeline systems and truck transfer requirements to fixed storage installations. Rail transport is also a concern. PHMSA prepared a DOT map of responsibilities that could be mirrored for hydrogen applications- https://www.phmsa.dot.gov/pipeline/liquified-natural-gas/jurisdiction-lng-plants	NREL component failure project and is evaluating key hydrogen fueling station components to determine root-cause failure and also measuring leak rates from these components to derive actual leak rate that could be used in risk analyses including in the HyRAM tool
Project 2. System siting including revised setback distances (and potentially measures for reducing setback distances) for bulk liquefied hydrogen storage systems and Guidance for application of safety setback distances in NFPA codes	NREL and Sandia are working together to develop both setback distances for bulk liquefied hydrogen storage systems based on engineering analysis and preventative and mitigating safety measures to reduce risk and give project developers additional options in siting these systems
Project 3. Existing Infrastructure transportation and vehicle including addition of material on hydrogen releases in tunnels and Parking garage chapter requires alignment with 88A Standard for Parking Structures	Sandia has performed analyses of hydrogen releases in tunnels to relieve restrictions on the use of FCEVs in tunnels systems. NREL has had this information incorporated in NFPA codes.
Project 4. Alternative fueling protocols to allow for greater flexibility in temperature range and vehicle types	NREL has worked to validate new fueling protocols and will evaluate the need for new fueling protocols for heavy duty vehicles and support these protocols as needed.

DOE national laboratory safety representatives evaluated and ranked projects to define path forward, which included project actions. NREL acted on directives.

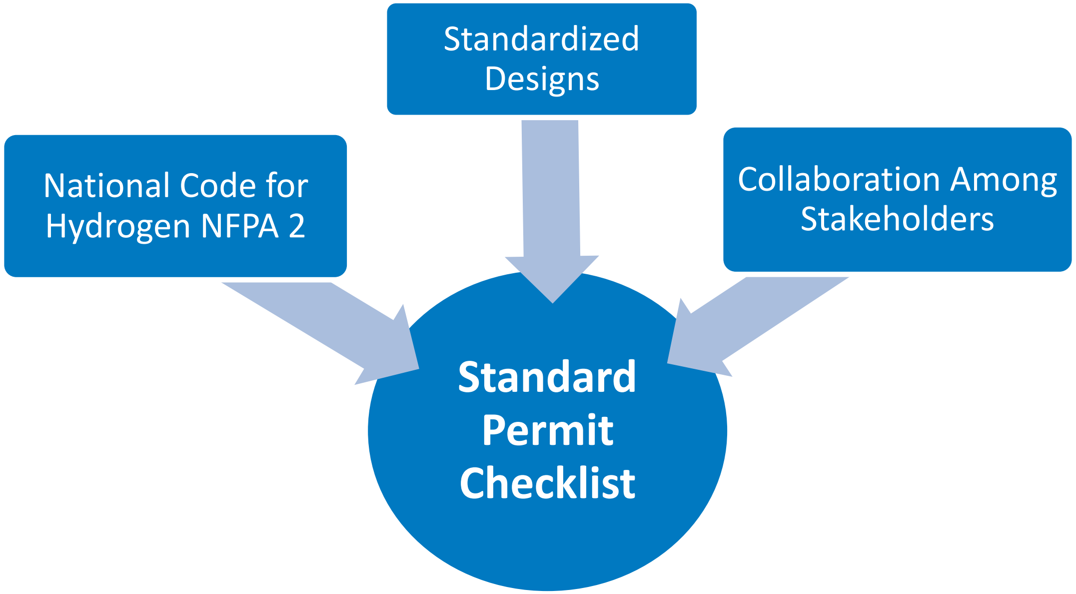
Accomplishments: Directed NFPA 2 Task Groups in Production of 2020 Hydrogen Technologies Code

NREL chaired the NFPA Hydrogen Technologies Technical Committee to direct the production of the 2020 edition of the NFPA 2 Hydrogen Technologies Code, including directing the task groups.



Impact: Chaired NFPA Hydrogen Technologies Technical Committee to direct the production of the 2020 edition of NFPA 2 Hydrogen Technologies Code, including directing the task groups to make changes closing code gaps

Accomplishments: Developed Standard Permit for Hydrogen Storage



Standard permits will accelerate infrastructure deployment without reducing public safety

- NREL formed NFPA 2 Standard Permit Task Group in January 2018
- Key permit identified as hydrogen station with gaseous/liquid storage
- Standard permit for gaseous/liquid HFSs completed in January 2019
- Group will continue to develop standard permits based on industry and safety needs

NREL-led NFPA 2 Permit Checklist Task Group developed standard permit checklist for station with gaseous/liquid storage that allows for relaxation of safety setback distances

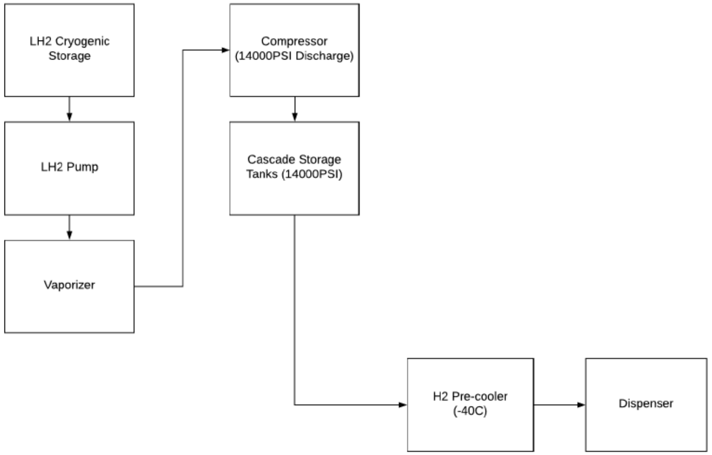
Accomplishment-Standard Permit Checklist

Key Permit Checklist Parameter

- Outdoor fueling
- Delivered hydrogen with storage systems that can be both bulk gaseous and liquefied hydrogen
- Addresses key requirements of 2016 edition of NFPA 2 but is not all inclusive
- Excel format
- Includes a basic station schematic that is matched to code chapters

Station schematic

LH2 Station, Trailer Liquid Supply, Cascade Fill



Impact: Standard permit checklist will accelerate deployment process while increasing the level of public safety by achieving more effective code compliance

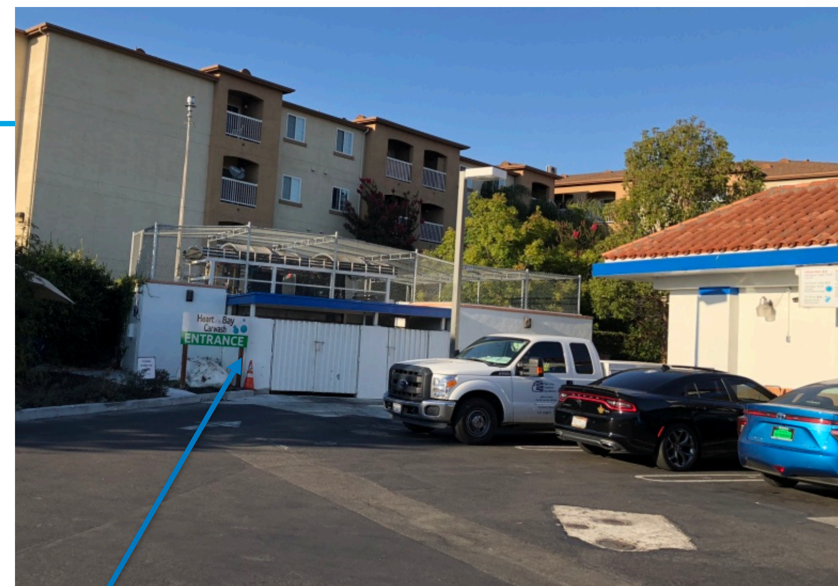
Accomplishments: Safety Distance Reduction by Hydrogen Storage Task Group

Table 7.3.2.3.1.1(A)(a) Minimum Distance (D) from Outdoor ~~[GH 2]~~ Bulk Hydrogen Compressed Gas Systems to Exposures — Typical Maximum Pipe Size [55:Table 10.4.2.2.1(a)]

Pressure	> 15 to ≤ 250 psig		> 250 to ≤ 3000 psig		> 3000 to ≤ 7500 psig		> 7500 to ≤ 15000 psig	
Internal Pipe Diameter (ID)	>103.4 to ≤ 1724 kPa		>1724 to ≤ 20,684 kPa		>20,684 to ≤ 51,711 kPa		>51,711 to ≤ 103,421 kPa	
d_{mm}	$d = 52.5_{mm}$		$d = 18.97_{mm}$		$d = 7.31_{mm}$		$d = 7.16_{mm}$	
Exposures Group 1	m	ft	m	ft	m	ft	m	ft
~~(a)~~ Lot lines	~~12~~ 5	~~40~~ 16	~~14~~ 6	~~46~~ 20	~~9~~ 4	~~29~~ 13	~~10~~ 5	~~34~~ 16
~~(b)~~ Air intakes (HVAC, compressors, other)								
~~(c)~~ Operable openings in buildings and structures								
~~(d)~~ Ignition sources such as open flames and welding								

Hydrogen Storage Task Group produced analysis and proposal to reduce safety setback distances for bulk gaseous hydrogen storage systems

Impact: Key reduction in safety setback Distances from 34 feet to 16 feet that should allow siting hydrogen fueling stations in space-constrained locations



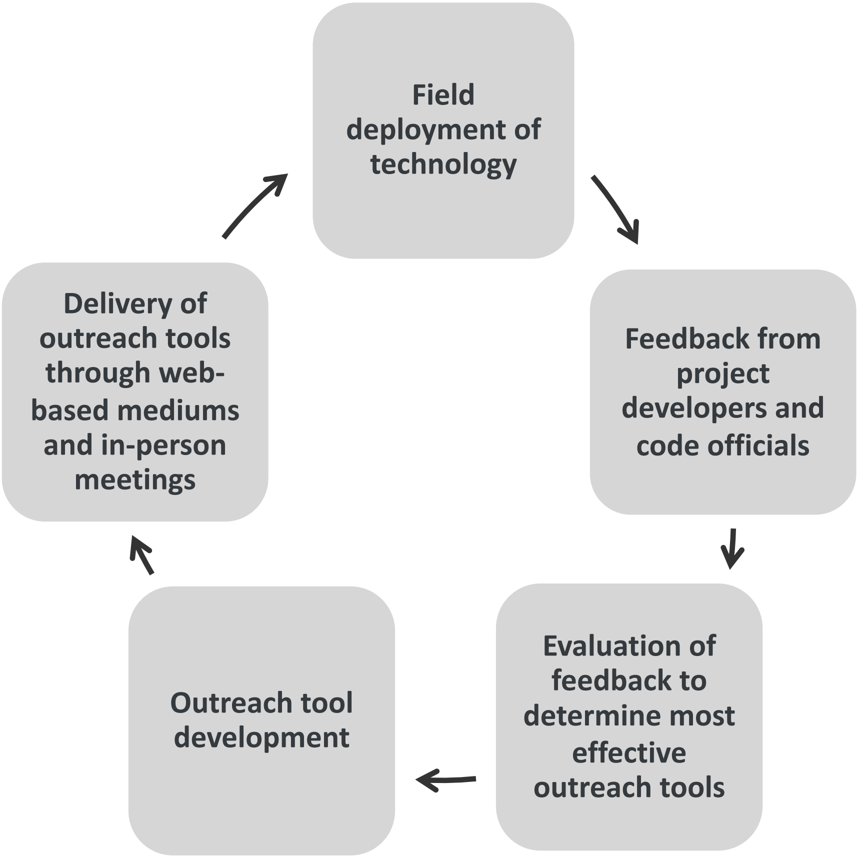
Hydrogen fueling site storage area with space constraints

Accomplishments and Progress: Delivered Outreach Tools and Guidance

Outreach Key Projects

- Maintained permitting tools at H2Tools
  - NFPA 2 training material
  - NREL technical reports
  - Code Official Training update
- Published papers, reports, and articles:
  - Safety Code equivalencies in Hydrogen Code Deployment
  - Hydrogen Fueling Station Component Failure Root-Cause Analysis
  - *Code official forum*
  - Two papers at the International Conference on Hydrogen Safety (ICHS), September 2017
  - Hydrogen Station Permitting Guide with code compliance tools

Outreach Process



Impact: Readily understood codes will lead to safer and faster deployment
https://h2tools.org/codes-standards/codes-standards-permitting-tools

Accomplishments and Progress: Component Failure Analysis

Project Objectives

- Identify components of concern at hydrogen stations
- Determine mechanism of failure
- Quantify leak rate on failed components
- Provide knowledge learned to station owners and hydrogen safety community

Project Partners

First Element - operates nineteen hydrogen fueling stations in California that include both gaseous and liquefied hydrogen storage

California State University, Los Angeles - operates a hydrogen fueling station that serves as both a retail fueling station and teaching station where students learn hydrogen infrastructure technology

NREL station showing storage, dispenser, and compression system

Accomplishments: Met first project deliverable of securing two station operators to provide failed components for root-cause failure analysis

Accomplishments and Progress: Component Failure Analysis

Component Test Plan

- Provide participating stations with failure data collection template, instructions, and sample collection kits
    - Requesting: Seals, gaskets, any fractured parts, replaced components (when possible)
- Conduct failure analysis on failed components/component parts
    - NREL will sequentially disassemble, conduct material identification, and use microscopy imaging to determine the root cause of failure
- Conduct leak quantification on failed components
- Compile results

Station Questionnaire

1. In your opinion, what are the most typical components that result in a hydrogen leak?
2. What is the most important recommended change that you would make to improve the station's reliability/safety?
3. What are your most frequently maintained components at the station?
4. What is in your spare parts inventory?
5. Since the opening of your station, have you updated any components with new designs or new manufacturers?
6. Is there any other information you would like to share with us in terms of station operation, safety, and maintenance?

Accomplishment: Produced project test plan to analyze failed components

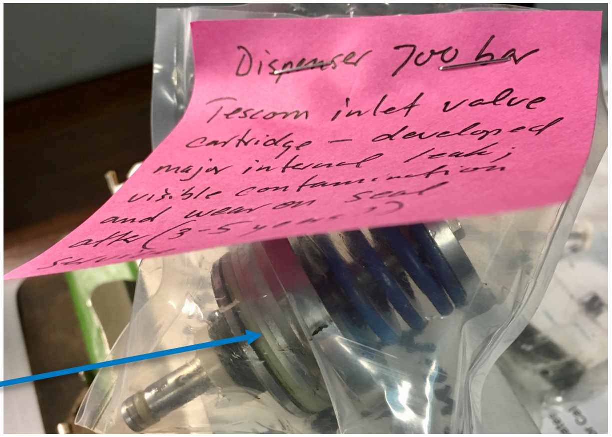
Accomplishments and Progress: Component Failure Analysis

Preliminary Results

- Internal leak to the dispenser, which caused the H2 sensor inside the dispenser to shut down PLC and power to the system before PLC was able to log the event electronically
- Ambient temperature around 10 C^{o}
- Leak happened after multiple fillings on a cool day
- It was discovered that the weep hole of the 700 bar inlet valve was positioned to be 12 inches below the H2 sensor
- Station operator saved the valve core for NREL analysis
- Particulate matter are observed on the valve core
- Soft goods deterioration due to thermal load and inadequate design are suspected as the root cause
- Station technician rebuilt the inlet valve with a new rebuild kit

Dispenser Key Process Location

- The 700 bar hose inlet valve inside the dispenser has been identified as a problematic component from various station operator interviews and manufacturer interviews.
- These inlet valves have had a mean failure time of 15,000 cycles at several stations, which translates to a life span of 6-10 months in the field, depending on use frequency.



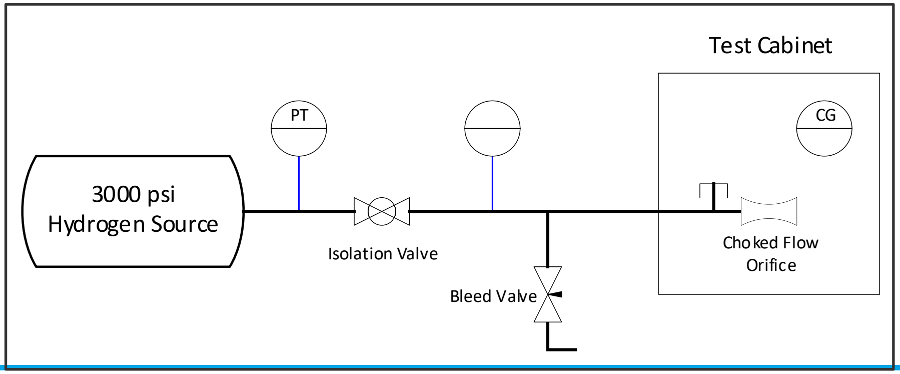
700 Bar inlet valve

Accomplishment: Collected key failed hydrogen fueling station components for root-cause analysis

Accomplishments and Progress: Component Failure Analysis

Leak Rate Measurement

- NREL has been given the opportunity by a project partner to measure leak rates from key station components
- NREL has developed a preliminary test plan to measure leak rates



Simplified diagram of the proposed test fixture as installed in a cabinet for testing. PT indicates a digital pressure measurement that is recorded for mass flow calculations. PI *indicates a pressure indicator used for zero energy verification.*

Key Measurement Locations

Dispenser cabinet - leaks are most typically small, relatively slow leaks through valves. The leaks may occur over a relatively long period of time and are detected when the concentration in the dispenser cabinet hits 25% of the LFL

Compressor systems - leaks develop from seal failures in compressor systems, resulting in larger hydrogen releases of shorter duration than dispenser leaks

Accomplishments: Measuring actual leak rate data from key components would allow for more accurate risk analysis and added flexibility in system siting

Accomplishments and Progress: Code Coordination

Coordination NFPA/ISO/CHC Vehicle Fueling Stations

- NREL presented at Canadian Hydrogen Installation Code (CHIC) meeting on February 21, 2019
- NREL will coordinate the requirements of NFPA 2 Hydrogen Technologies Code, the CHIC, and ISO/DTR 19880-1 for Gaseous hydrogen — Fueling stations — General requirements, to eliminate major conflicts where possible
  - Key areas of coordination include:
  - Safety separation distances for bulk hydrogen storage systems
  - Risk-analysis procedures
  - Safety equivalency procedures and application
  - Integration of standard fueling protocols into operational code requirements

Coordination Areas Between NFPA 2

Safety Requirement	NFPA 2	CHIC
Scope	1.3.1 This code shall apply to the production, storage, transfer, and use of hydrogen in all occupancies and on all premises.	Installation requirements for hydrogen generating equipment, hydrogen utilizing equipment, hydrogen dispensing equipment, hydrogen storage containers, hydrogen piping systems, and their related accessories
HAZOP	A hazard analysis shall be conducted on every hydrogen fueling system installation by a qualified engineer(s) with proven expertise in hydrogen fueling systems, and hazard analysis techniques.	Annex provides guidance

Impact: Major codes and standards that address hydrogen vehicle fueling will be coordinated to the extent possible

Accomplishments and Progress: Responses to Previous Year’s Reviewer Comments

- **Comment:** How will the standard permitting concept be implemented to achieve maximum impact?
- **Response:** The development of a “standard” permitting guide should dramatically help reduce time and cost for permitting hydrogen fueling station deployment. When asked how to reach the 44,000 Authorities Having Jurisdiction, the answer was to put this as an appendix on NFPA 2, which has already been adopted (in one way or another) in every state in the nation. It was an excellent answer.

Collaboration and Coordination

Collaborator	Project Impact
Industrial gas companies	These companies are major contributors to NFPA Hydrogen Storage Task Group and NFPA 2, 2020 edition
Station installers/developers, including First Element, Linde, Air Products, and Air Liquide	NREL has worked with station developers on the component failure project and to develop permitting tools
Standards development organizations (SDOs), including NFPA, CGA, SAE, CSA, UL, ISO, BNQ, ICC, ASME, and ASTM	NREL has served on multiple SDO technical committees and worked to integrate NREL research into codes and standards
DOE national laboratories	Sandia National Laboratories, Pacific Northwest National Laboratory, Lawrence Livermore National Laboratory, and Los Alamos National Laboratory are part of IRIG and NFPA Task Groups
Regional fire and building officials, including California Fire Marshal's Office and Massachusetts Fire Marshal's Office	NREL provided information and outreach events to support project activity in jurisdictions where hydrogen technologies are being deployed
Regional hydrogen advocacy groups, including Colorado Hydrogen Coalition and California Fuel Cell Partnership	NREL provided input on the development of state regulations

NREL has worked with all stakeholders to achieve the maximum impact on hydrogen technologies safety.

Remaining Challenges and Barriers

Challenges	Path Forward
Hydrogen safety issues identified in the range of applications dictated by H2@Scale	Evaluate hydrogen safety issues and identify actions required to address these issues
The code compliance process can be complicated, leading to noncompliance	Develop standard permits for common project configurations on an ongoing basis
Code users may be infrequent or new users	Develop tools in the most effective format to get users quickly oriented to the applicable requirements, including placing support material in Annex of NFPA 2 and H2Tools website (where it will be readily seen), and developing a hydrogen Fueling Station Permitting Guide
Different jurisdictions may use different codes or different code editions	Support the national and international application of commonly adopted documents such as NFPA 2 Hydrogen Technologies Code so that requirements are standardized across jurisdictions

Proposed Future Work

- Address key safety issues to enable H2@Scale hydrogen deployment including the following:
  - Measure leak rates from components to develop leak rate data that can be used in models such as HyRAM
  - Identify root-cause for component failures and recommend preventive and mitigative actions to reduce failure frequency
  - Structure hydrogen vehicle fueling requirements to better match infrastructure projects
  - Publish Hydrogen Fueling Station Permitting Guide
  - Address safety needs for H2@Scale projects including large hydrogen production, storage, and distribution systems
  - Continue to identify the needs of safety information users and provide information to meet those needs in the most accessible and intelligible form possible.

Any proposed future work is subject to change based on funding levels

Summary

- NREL's CCSI and safety outreach activities advance hydrogen technologies safety by:
  - Integrating research and development activities into codes and standards development
  - Transferring lessons learned from the field into the code development process to improve codes and identify research needs
  - Identifying gaps in codes and standards based on feedback from all interested parties and producing plans to fill these code gaps, including research needs
  - Distributing information on codes and standards and project permitting to interested parties in a format and with a level of detail most suited to their needs
  - Performing all of these activities with the widest collaboration with all interested parties.

NREL integrates research into safety requirements to safely advance hydrogen technologies in all applications.

Thank You

www.nrel.gov

Publication Number

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