Enabling Hydrogen Infrastructure Through Science-based Codes and Standards

Chris LaFleur
Sandia National Laboratories
Livermore, CA and Albuquerque, NM

June 11, 2015

Project ID SCS025

2015 DOE Hydrogen and Fuel Cells Annual Merit Review

This presentation does not contain any proprietary, confidential, or otherwise restricted information.
Overview

Timeline
- Project start date: Oct. 2003
- Project end date: Sept. 2015*
* Project continuation and direction determined by DOE annually.

Barriers
D. Lack of Hydrogen Knowledge by AHJs
G. Insufficient technical data to revise standards
H. Insufficient Synchronization of National Codes and Standards
K. No Consistent Codification Plan and Process for Synchronization of R&D and Code Development

Budget
- FY14 DOE Funding: $1.0M
- Planned FY15 DOE Funding: $1.2M
- Total DOE Project Value: $22M

(Funding numbers include SCS#010, SCS#011 and SCS#025: Behavior, Risk and Infrastructure/Code program elements)

Partners
Industry & research collaborators:
Linde, Air Products and Chemicals Inc., HySafe

SDO/CDO participation:
NFPA2, CSA HGV4.9, ISO TC197

International engagement:
HySafe, HyIndoor, IEA HIA Task 31
**Objective**: Enable the growth of hydrogen infrastructure through science and engineering-based Codes and Standards

- Streamline cost and time for station permitting by demonstration of alternative approaches to code compliance
- Revise/update codes & standards that address critical limitations to station implementation

### Barrier from 2013 SCS MYRDD

<table>
<thead>
<tr>
<th>Barrier from 2013 SCS MYRDD</th>
<th>SNL Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>D. Lack of Hydrogen Knowledge by AHJs</td>
<td>Develop and demonstrate risk-equivalent station design and socialize with real-world AHJ</td>
</tr>
<tr>
<td>F. Insufficient technical data to revise standards</td>
<td>Build tools to enable industry-led C&amp;S revision and safety analyses to be based on a strong science &amp; engineering basis</td>
</tr>
<tr>
<td>H. Insufficient Synchronization of National Codes and Standards</td>
<td>Apply H2-specific QRA tools &amp; methods to support code decisions and to enable risk-equivalent code compliance option</td>
</tr>
<tr>
<td>K. No Consistent Codification Plan and Process for Synchronization of R&amp;D and Code Development</td>
<td></td>
</tr>
</tbody>
</table>
SNL Hydrogen Safety Program Approach

The Safety, Codes and Standards program coordinates critical stakeholders and research to remove technology deployment barriers.

- **Identify R&D needs**
- **Perform High-Priority R&D**
- **Impact Codes and Standards**

**Harmonize Internationally**
- Regulations, Codes and Standards [RCS]
- International Standards (ISO)
- International Agreements (IEA, IPHE)

Partnerships with industry, labs, academia
Approach: Enabling Hydrogen Infrastructure

Alternative Methods for Code Compliant Hydrogen Infrastructure

Science-based Code Revisions to Address Critical Limitations to Station Implementation
### Approach / FY14-15 Milestones

#### Alternative Methods for Code Compliance for Refueling Station

<table>
<thead>
<tr>
<th>Activity</th>
<th>Completion date or status</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Develop a Template for Utilizing QRA in a Performance-based Design</td>
<td></td>
</tr>
<tr>
<td>• H2First Reference Liquid Station for design specification</td>
<td>Dec 2014</td>
</tr>
<tr>
<td>• Milestone Deliverable – Issue Draft Template of performance-based design (PBD)</td>
<td>Jan 2015</td>
</tr>
<tr>
<td>• Publish Final Template</td>
<td>Ongoing (95%)</td>
</tr>
<tr>
<td>• Demonstrate Performance-based Design for a Real-world station</td>
<td></td>
</tr>
<tr>
<td>• CRADA with Linde for real-world station</td>
<td>August 2014</td>
</tr>
<tr>
<td>• Station selection – Foster City</td>
<td>Oct 2014</td>
</tr>
<tr>
<td>• AHJ socialization and education</td>
<td>Nov 2014</td>
</tr>
<tr>
<td>• Develop PBD design, justification and station permitting</td>
<td>Ongoing (75%)</td>
</tr>
</tbody>
</table>

#### Science-based Code Improvements

<table>
<thead>
<tr>
<th>Activity</th>
<th>Completion date or status</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Update Science Basis of Liquid Separation Distances in NFPA 2/55</td>
<td></td>
</tr>
<tr>
<td>• Identify Scenarios of Concern for Basis of Code Revision</td>
<td>Apr 2015</td>
</tr>
<tr>
<td>• Identify Modeling Gaps for Liquid Release Characterization</td>
<td>Ongoing (25%)</td>
</tr>
<tr>
<td>• Develop Risk-Informed Separation Distance Revision Proposals to Code</td>
<td>Ongoing (10%)</td>
</tr>
<tr>
<td>• Conduct Mitigations Forum</td>
<td>Apr 2015</td>
</tr>
<tr>
<td>• Host Mitigations Forum of hydrogen experts</td>
<td>June 2015</td>
</tr>
<tr>
<td>• Identify research gaps in valuation and crediting of hydrogen system safety features</td>
<td></td>
</tr>
<tr>
<td>• Synchronize with International Standards</td>
<td></td>
</tr>
<tr>
<td>• ISO TC 197 Working Group</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>
Approach: Key Barrier – Prescriptive LH2 Separation Distances

- Current bulk distance values
  - Based on historical values
  - Present critical limitation to hydrogen infrastructure growth

- **Science-based Code Improvements** - Ongoing effort by NFPA 2 subcommittee to revise based on risk-informed science of LH2 release behavior. Best case schedule for 2019 code edition, jurisdictional adoption later

- **Alternative Methods for Code Compliance** - In the meantime, this effort is exploring a path forward for short term deviation from separation distances for LH2
Approach: Alternative Methods for Code Compliance

- NFPA 2 (*Hydrogen Technologies Code*) specifically allows performance-based designs for hydrogen facilities. Performance-based designs (PBD) enable alternate specifications that do not conform with the prescriptive code requirements, but ensure *equivalent safety* through the use of performance criteria.

- Performance-based design solutions have not been developed for hydrogen applications due to:
  - Perceptions that PBD is cost prohibitive
  - Uncertainty surrounding acceptance by (AHJs) due to lack of familiarity with risk methods
  - Lack of validated methodology
Approach: Application of QRA to Performance-Based Design

Representative Station: H2FIRST Reference Liquid Station
- Meets all Prescriptive Requirements
- Calculate Benchmark Performance Criteria
- Vet with H2 Code Industry and Stakeholders

Performance-Based Design of Refueling Station
- Modifies Key Requirements
- Incorporate Mitigating Factors
- Calculate Risk Risk Equivalent Performance Criteria

Real-World Station: Linde Foster City
- Modifies One Key Requirement and Incorporates Mitigating Factors
- Prepare Performance-Based Design Report and Documentation Utilizing HyRAM QRA Toolkit
- Follows Real-World Permitting Process
Approach: Performance-based Design Process

- Template follows standard process developed by NFPA and SFPE
- All components of the Design Brief are included in the Template
- Performance-based design and mock permitting documents will be submitted to industry experts and experienced AHJs for vetting
Accomplishment: Template of Performance-based Design of H2 Fueling Station Completed

- **Goal:** Demonstrate the use of QRA methods to develop and implement a Performance-Based Design (PBD) for hydrogen infrastructure
  - Sandia Developed Hydrogen Risk Assessment Models (HyRAM) was used for QRA calculations (see SCS-0011)
  - PBD promotes safety through use of performance criteria rather than explicit prescriptive requirements
  - Enables a risk-informed compliance option

- A Design Brief Template has been prepared utilizing the H2FIRST Reference Station
  - Approach will be vetted in hydrogen industry and AHJ’s covering stations in California

Developed a template of a viable PBD approach to code compliance that facilitates industry use, AHJ acceptance, and leads to improved PBD requirements in the codes
Accomplishment: Hosted H2 Mitigations Forum

- **Goals:** Identify and prioritize R&D activities for evaluating and crediting safety features that mitigate system risks

- **Organized and hosted by SNL** – Albuquerque NM, April 2015
  - Participants from: SNL, DOE FCTO, Air Liquide, Linde, Praxair, Air Products, NASA, NREL, PNNL

- **Key Outcomes:**
  - List of research gaps in ability to quantify risk mitigating safety features:
    - Highlight opportunities for advancement of mitigation strategies
    - Identify further opportunities for science-based code enhancement
  - Identified methods for quantifying and establishing safety credit for mitigations:
    - Prioritized list of available methods
    - Prioritized list of mitigation safety features – code-required and optional

Main R&D priorities: Develop a feasible method to quantify and credit risk-mitigating safety features and inform code requirements.
Accomplishment: ISO Code Work

- **Goal:** Support development of ISO TR-19880-1, *Gaseous Hydrogen- Fueling Stations Part 1: General Requirements*

- **Progress:**
  - Incorporating QRA/safety assessment method and mitigation options into Chapter 4 of the Standard
  - Selected ISO members are also Alpha Testers of HyRAM

Synchronization of international codes with a risk- and hydrogen specific behavior-basis
Accomplishment: Informing Science-based Code Revisions

- **Goal:** Use QRA tools and methods to revise bulk liquid hydrogen system separation distances in NFPA 55/NFPA 2

- **Progress:**
  - Developing scientific framework to select scenarios that will be used to determine basis of revised separation distances
  - Providing technical leadership and hydrogen release behavior models to incorporate current science and technology information to risk-inform code requirements

**Validated LH2 release model will be used to risk-inform the revised LH2 bulk separation distances in the 2019 code cycle**
Response to Previous Year Reviewers’ Comments

- This effort was not reviewed at the 2014 AMR
- Portions of this were communicated in the 2014 SCS-011 presentation: Hydrogen behavior and Quantitative Risk Assessment
- Reviewer Comments on this project
  - AMR2014 comment: “The work absolutely has the potential to affect code in a positive way (reducing quantity-distance restrictions, thus making fueling stations fit better in current footprints). The largest hurdle is going to be getting code officials to understand this QRA approach and to adopt it. The current project does not have a planned goal for this, however.”
- Response: Engaging with code officials is critical, and SNL is pursuing multiple avenues for doing this including presenting an overview of hydrogen risk tools and methods to AHJs, targeted code officials, and other fire protection industry organizations.
# Collaborations

## CRADA

<table>
<thead>
<tr>
<th>Relationship</th>
<th>Partner</th>
<th>FY 14 - FY15 Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRADA</td>
<td><strong>Industry:</strong> Linde Group, Industrial gas supplier (Hayward, CA)</td>
<td>Signed CRADA - In-kind support, data exchange for QRA tool and QRA demonstration activities, hydrogen mitigations forum</td>
</tr>
</tbody>
</table>

## Collaborator

<table>
<thead>
<tr>
<th>Relationship</th>
<th>Partner</th>
<th>FY 14 - FY15 Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collaborator</td>
<td><strong>International:</strong> HySafe</td>
<td>Technical exchanges, ISO</td>
</tr>
<tr>
<td>Collaborator</td>
<td><strong>Industry:</strong> Air Liquide, Praxair, Air Products</td>
<td>Collaboration in hydrogen mitigations forum</td>
</tr>
<tr>
<td>Collaborator</td>
<td><strong>Federal Laboratory:</strong> Pacific Northwest National Laboratory</td>
<td>Hydrogen tools portal, Hydrogen Safety Panel, hydrogen mitigations forum</td>
</tr>
<tr>
<td>Collaborator</td>
<td><strong>Federal Laboratory:</strong> National Renewable Energy Laboratory</td>
<td>Safety code and standard committee leadership, hydrogen mitigations forum</td>
</tr>
</tbody>
</table>

## SDO/CDO memberships

- NFPA 2
- ICC
- ISO TC 197 WG24
- CGA
- CSA HGV4.9

## Organization memberships*

- HySafe
- IEA HIA Task 31
- H2USA Locations WG
- H2USA Stations WG
- DOE CSTT

## Technical exchanges, presentations & discussions

- CaCFP, ASME
- DOE Hydrogen Safety Panel, DOT FRA
- PNNL, NREL
- AIST (Japan), HyIndoor (EU)
Remaining Challenges and Barriers

- **Alternative Methods**
  - Agreement between real world station owner and hydrogen supplier is not reached in time to develop performance-based design option prior to October 2015 funding subsidy
  - Local AHJ acceptance of a performance based design of a hydrogen refueling station

- **Science-based Code Improvements**
  - Insufficient industry participation as stakeholders in cold plume release validation experiments
  - Validation of the cold plume release model is not completed in time for the public comment code cycle, or does not characterize liquid release scenarios needed for code committee revisions to bulk liquid hydrogen separation distance table
  - Consensus agreement on suitable means of quantifying hydrogen system mitigation features is not reached
Proposed Future Work

- **Remainder of FY15**
  - **Alternative Methods**: Support permitting of real world station by October 31, 2015
  - **Science-based Code Improvements**: Identify research gaps in evaluating and prioritizing mitigation features in hydrogen systems

- **FY16**
  - **Alternative Methods**: Extend performance-based design template to other hydrogen applications where an alternative solution is needed
  - **Science-based Code Improvements**: Use validated LH2 release model to characterize bulk liquid release scenarios to revise separation distances.

- **Out-years**
  - Apply validated liquefied hydrogen release models to enable alternative methods to directly address limiting separation distance. Develop risk-informed separation distance proposals to NFPA 55/NFPA 2.
  - Update bulk gaseous separation distances requirements based on new data
  - Continue synchronization risk-informed codes: ISO, ICC, NFPA
  - Expand science- and risk-based code improvements to other alternative fuels
Technology Transfer Activities

- Technology transfer strategies are tied to the accessibility of HyRAM QRA tool kit to other users (AHJs, Station designers, etc.) utilizing alternative means of code compliance
- Refer to AMR SCS-011 presentation
Summary

• **Mitigations Forum:**
  - Addresses: Reducing barriers related to lack of technical data for SCS revision
  - By: Identifying research gaps and developing scientific framework for crediting hydrogen system safety features

• **PBD Template**
  - Addresses: Education of AHJs,
  - By: Validating and demonstrating alternative methods of code compliance

• **Science-based Code Improvements**
  - Addresses: Reducing barriers related to lack of technical data for SCS revision
  - By: Providing expertise to support science-based code revisions of bulk LH2 separation distances

• **ISO TC 197**
  - Addresses: Synchronization with international codes
  - By: Active technical leadership on working groups revising risk-based methodology
Technical Back-Up Slides
Performance-Based Design Required Scenarios
Specified in NFPA 2, *Hydrogen Technologies Code*

- Fire
- Explosions
  - Pressure Vessel Burst
  - Hydrogen Deflagration
  - Hydrogen Detonation
- Hazardous Materials
  - Unauthorized Release
  - Exposure Fire
  - External Factor
  - Discharge with Protection System Failure
### NFPA 2 Performance-Based Design: Explosion Scenarios

<table>
<thead>
<tr>
<th>Scenario Description</th>
<th>Performance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Outdoor Fueling Station Scenario</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Fire</strong></td>
<td>5.4.2: Design for life safety</td>
</tr>
<tr>
<td></td>
<td>Hydrogen fire resulting from a leak at the dispenser</td>
</tr>
<tr>
<td></td>
<td>HyRAM jet fire risk calculation</td>
</tr>
<tr>
<td><strong>Pressure Vessel Burst</strong></td>
<td>5.4.3.1: Pressure vessel ruptures</td>
</tr>
<tr>
<td></td>
<td>Prevention of gaseous H2 vessel rupture</td>
</tr>
<tr>
<td><strong>Hydrogen Deflagration</strong></td>
<td>5.4.3.2: Deflagration of a hydrogen-air or hydrogen-oxidant mixture within large process equipment</td>
</tr>
<tr>
<td></td>
<td>Deflagration within the enclosure housing the compressor</td>
</tr>
<tr>
<td></td>
<td>HyRAM peak overpressure and risk metric calculation</td>
</tr>
<tr>
<td><strong>Hydrogen Detonation</strong></td>
<td>5.4.3.3: Detonation of a hydrogen-air or hydrogen-oxidant mixture within a process vessel or within piping containing hydrogen</td>
</tr>
<tr>
<td></td>
<td>Unintended release forms localized H2/air mixture that detonates</td>
</tr>
<tr>
<td></td>
<td>Prevention of detonation by meeting vent pipe length to diameter ratio</td>
</tr>
</tbody>
</table>
### Scenario Description

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unauthorized Release</strong></td>
<td>5.4.4.1: Unauthorized release from a single control area</td>
</tr>
<tr>
<td></td>
<td>Accidental release of hydrogen from liquid storage tank</td>
</tr>
<tr>
<td></td>
<td>Liquid hydrogen release model analysis</td>
</tr>
<tr>
<td><strong>Exposure Fire</strong></td>
<td>5.4.4.2: Exposure fire on a location where hydrogen is being stored, used, handled or dispensed</td>
</tr>
<tr>
<td></td>
<td>An unrelated car fire at the gasoline dispensing pump</td>
</tr>
<tr>
<td></td>
<td>Characterization of flame radiation from vehicle fire on nearest hydrogen system components</td>
</tr>
<tr>
<td><strong>External Factor</strong></td>
<td>5.4.4.3: Application of an external factor that is likely to result in a fire, explosion, toxic release or other unsafe condition</td>
</tr>
<tr>
<td></td>
<td>Seismic Event where a pipe bursts (100% Leak Size on largest system pipe)</td>
</tr>
<tr>
<td></td>
<td>HyRAM risk metric calculation</td>
</tr>
<tr>
<td><strong>Discharge with protection system failure</strong></td>
<td>5.4.4.4: Unauthorized discharge with each protection system independently rendered ineffective</td>
</tr>
<tr>
<td></td>
<td>An unauthorized discharge where the interlock or pressure relief valve fails</td>
</tr>
<tr>
<td></td>
<td>Discussion of layered safety features present in the system</td>
</tr>
</tbody>
</table>
### Egress System

<table>
<thead>
<tr>
<th>Scenario Description</th>
<th>Discussion of Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.4.2: Design for life safety affecting the egress system</td>
<td>No egress system since fueling station is outdoors</td>
</tr>
</tbody>
</table>

### Max Occupant Load with Blocked Exit

<table>
<thead>
<tr>
<th>Scenario Description</th>
<th>Discussion of Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.4.5.1: Maximum occupant load is in the assembly building and the principal exit/entrance is blocked</td>
<td>No assembly occupancies in the vicinity and no exits to block</td>
</tr>
</tbody>
</table>

### Construction in area of building with suppression system out of service

<table>
<thead>
<tr>
<th>Scenario Description</th>
<th>Discussion of Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.4.5.2: Fire in an area of the building undergoing construction while remainder of building is occupied. The suppression system has been taken out of service.</td>
<td>No partially-occupied buildings with suppression system out of service to analyze</td>
</tr>
</tbody>
</table>
Method to calculate mitigations (standardized, with flexibility in model choice)

Green boxes: Required for all analyses (define analysis & model consequences)

Blue boxes: Optional (for countries using the full risk-informed approach) – allows take credit for risk-reduction