Enabling Hydrogen Infrastructure Through Science-based Codes and Standards

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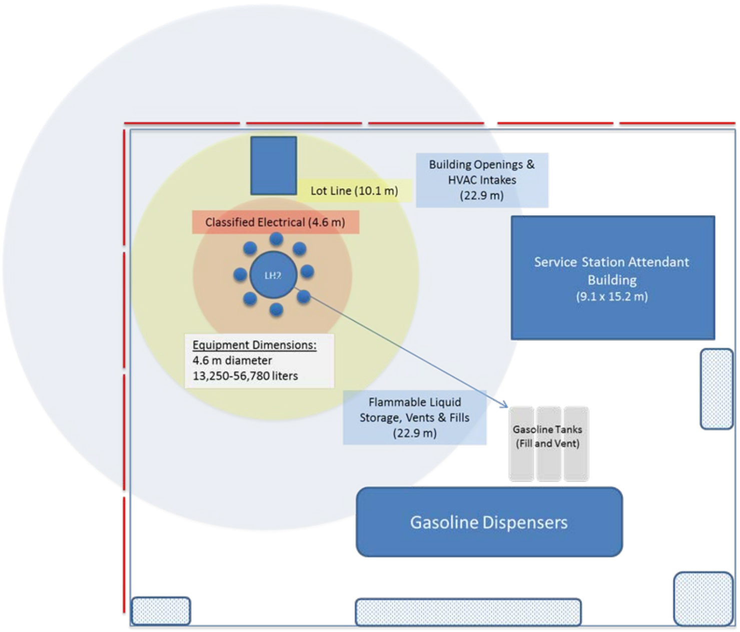

Project ID SCS025

2015 DOE Hydrogen and Fuel Cells Annual Merit Review

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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

Relevance

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	SNL Goal
D. Lack of Hydrogen Knowledge by AHJs	Develop and demonstrate risk-equivalent station design and socialize with real-world AHJ
F. Insufficient technical data to revise standards	Build tools to enable industry-led C&S revision and safety analyses to be based on a strong science & engineering basis
H. Insufficient Synchronization of National Codes and Standards K. No Consistent Codification Plan and Process for Synchronization of R&D and Code Development	Apply H2-specific QRA tools & methods to support code decisions and to enable risk-equivalent code compliance option

SNL Hydrogen Safety Program Approach

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

Partnerships with industry, labs, academia

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

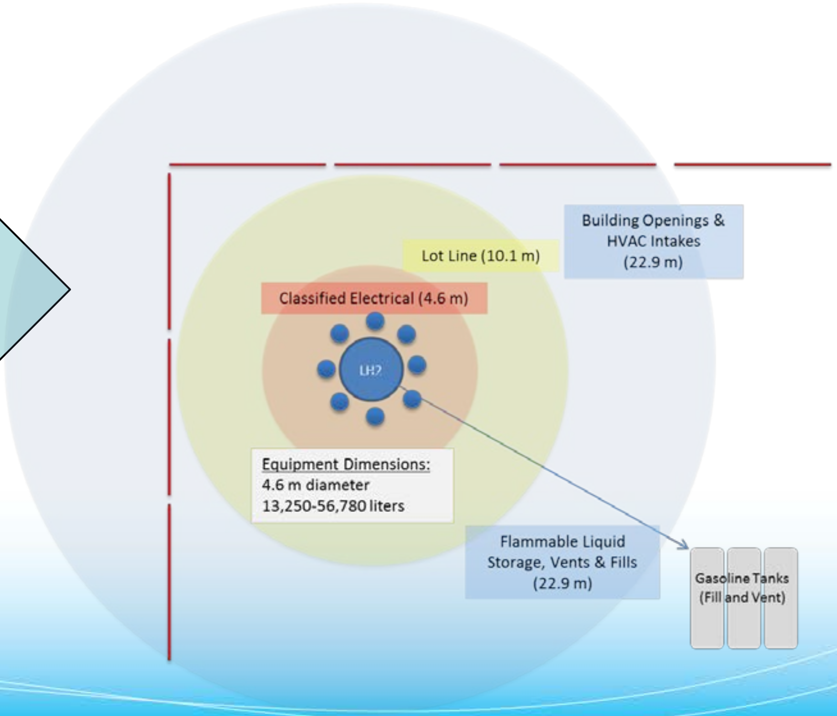
Harmonize Internationally

Regulations, Codes and Standards [RCS]
International Standards (ISO)
International Agreements (IEA, IPHE)

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

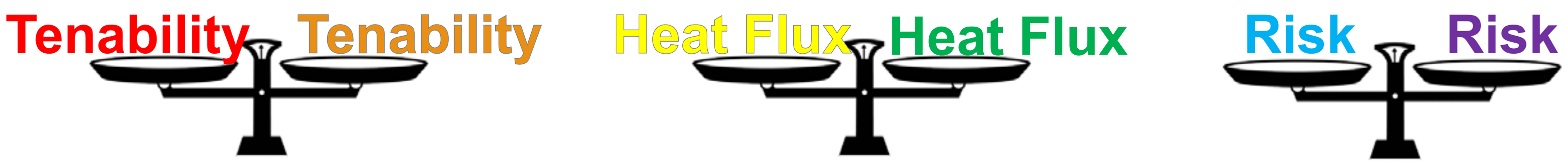
Alternative Methods for Code Compliance for Refueling Station	Completion date or status
• **Develop a Template for Utilizing QRA in a Performance-based Design**	
• H2First Reference Liquid Station for design specification • Milestone Deliverable – Issue Draft Template of performance-based design (PBD) • Publish Final Template	Dec 2014 Jan 2015 Ongoing (95%)
• **Demonstrate Performance-based Design for a Real-world station**	
• CRADA with Linde for real-world station • Station selection – Foster City • AHJ socialization and education • Develop PBD design, justification and station permitting	August 2014 Oct 2014 Nov 2014 Ongoing (75%)
Science-based Code Improvements	
• **Update Science Basis of Liquid Separation Distances in NFPA 2/55**	
• Identify Scenarios of Concern for Basis of Code Revision • Identify Modeling Gaps for Liquid Release Characterization • Develop Risk-Informed Separation Distance Revision Proposals to Code	Apr 2015 Ongoing (25%) Ongoing (10%)
• **Conduct Mitigations Forum**	
• Host Mitigations Forum of hydrogen experts • Identify research gaps in valuation and crediting of hydrogen system safety features	Apr 2015 June 2015
• **Synchronize with International Standards**	
• ISO TC 197 Working Group	Ongoing

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.



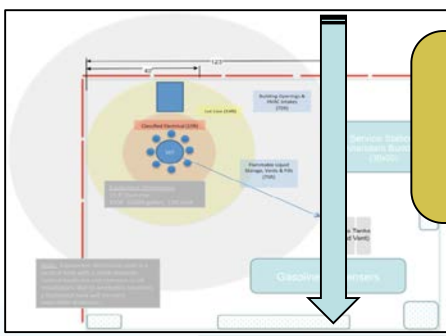
- Performance-based design solutions have not been developed for hydrogen applications due to:
  - Perceptions that PBD is cost prohibitive
  - Uncertainty surrounding acceptance by (AHJs) due to lack of familiarity with risk methods
  - Lack of validated methodology

Approach: Application of QRA to Performance-Based Design

Performance-Based Design of Refueling Station

Representative Station: **H2FIRST Reference Liquid Station**

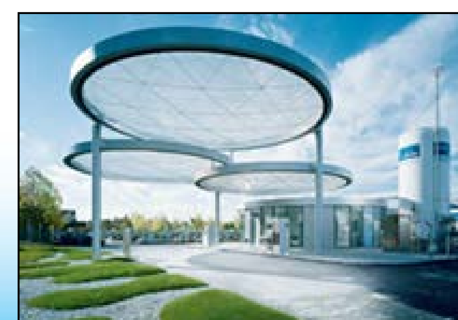
- Meets all Prescriptive Requirements
  - Calculate Benchmark Performance Criteria
- Modifies Key Requirements
  - Incorporate Mitigating Factors
  - Calculate Risk Risk Equivalent Performance Criteria



Vet with H2 Code Industry and Stakeholders

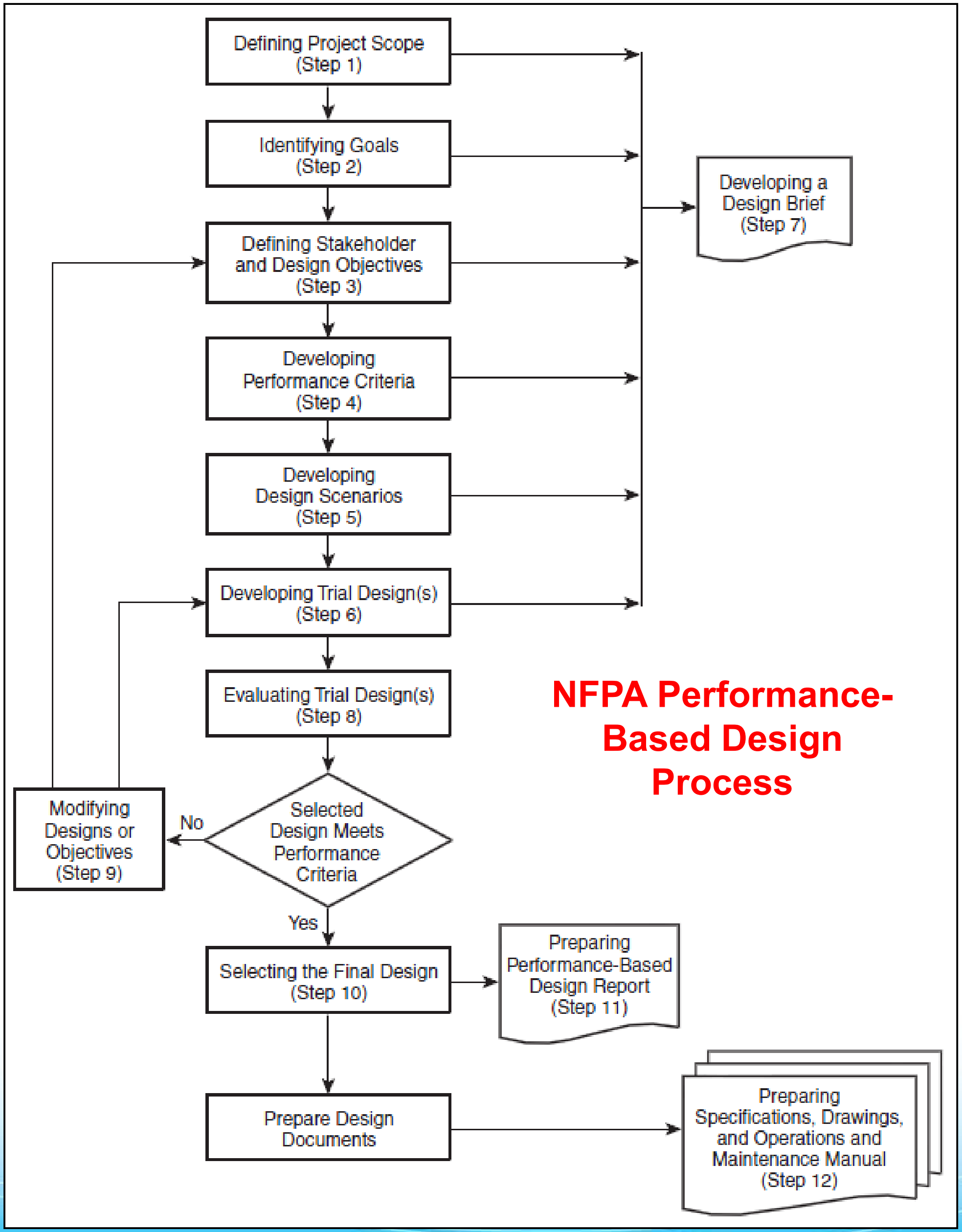
Real-World Station: **Linde Foster City**

- 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

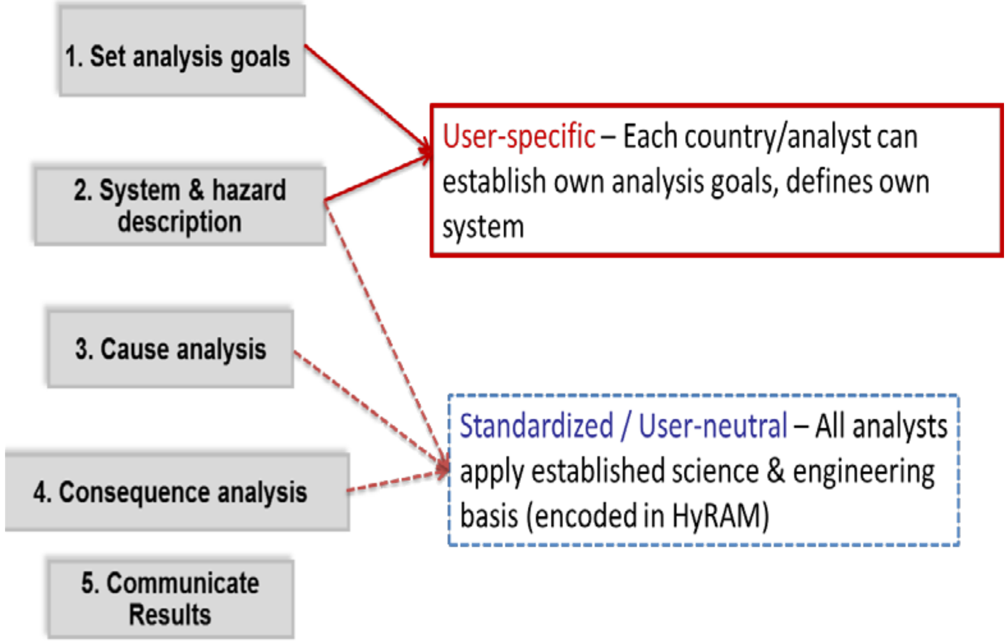
Accomplishment: Hosted H2 Mitigations Forum

- **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

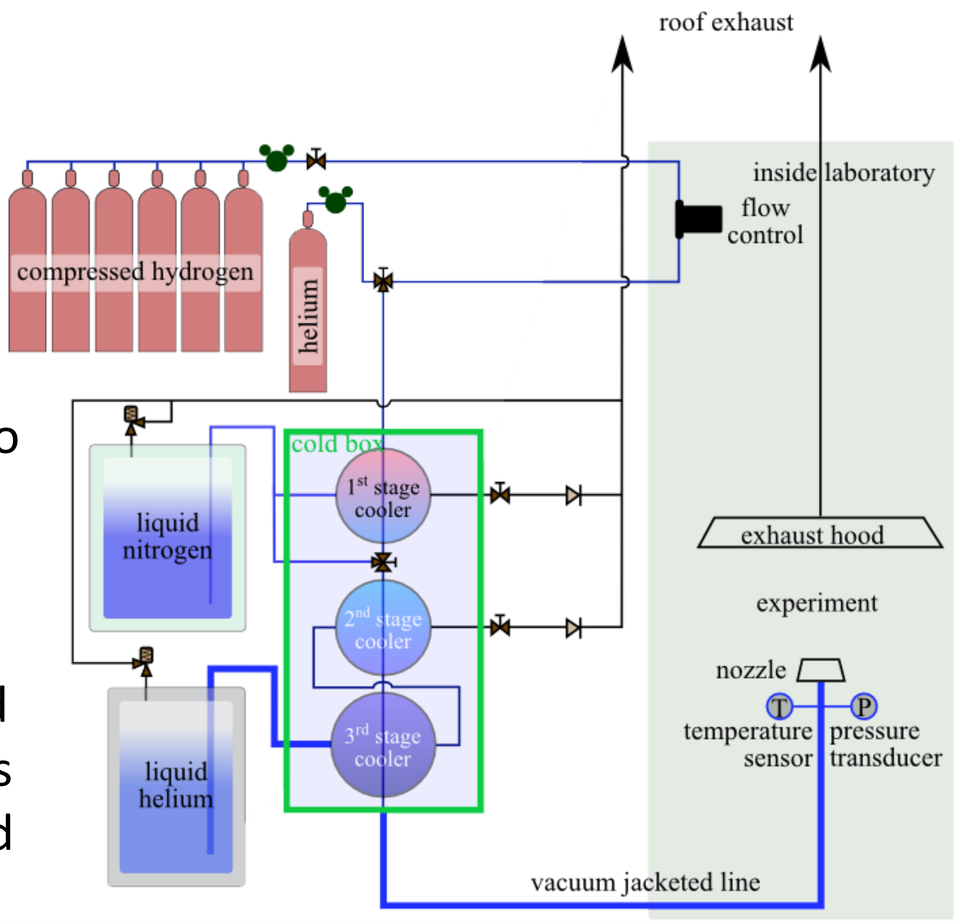
- **Goal:** Support development of ISO TR-19880-1, *Gaseous Hydrogen- Fueling Stations Part 1: General Requirements*
- Progress:
  - Incorporating QRA/safety assessment method and mitigation options into Chapter 4 of the Standard
  - Selected ISO members are also Alpha Testers of HyRAM



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

Relationship	Partner	FY 14 - FY15 Role
CRADA	**Industry:** Linde Group, Industrial gas supplier (Hayward, CA)	Signed CRADA - In-kind support, data exchange for QRA tool and QRA demonstration activities, hydrogen mitigations forum
Collaborator	**International :** HySafe	Technical exchanges, ISO
Collaborator	**Industry**: Air Liquide, Praxair, Air Products	Collaboration in hydrogen mitigations forum
Collaborator	**Federal Laboratory**: Pacific Northwest National Laboratory	Hydrogen tools portal, Hydrogen Safety Panel, hydrogen mitigations forum
Collaborator	**Federal Laboratory**: National Renewable Energy Laboratory	Safety code and standard committee leadership, hydrogen mitigations forum

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

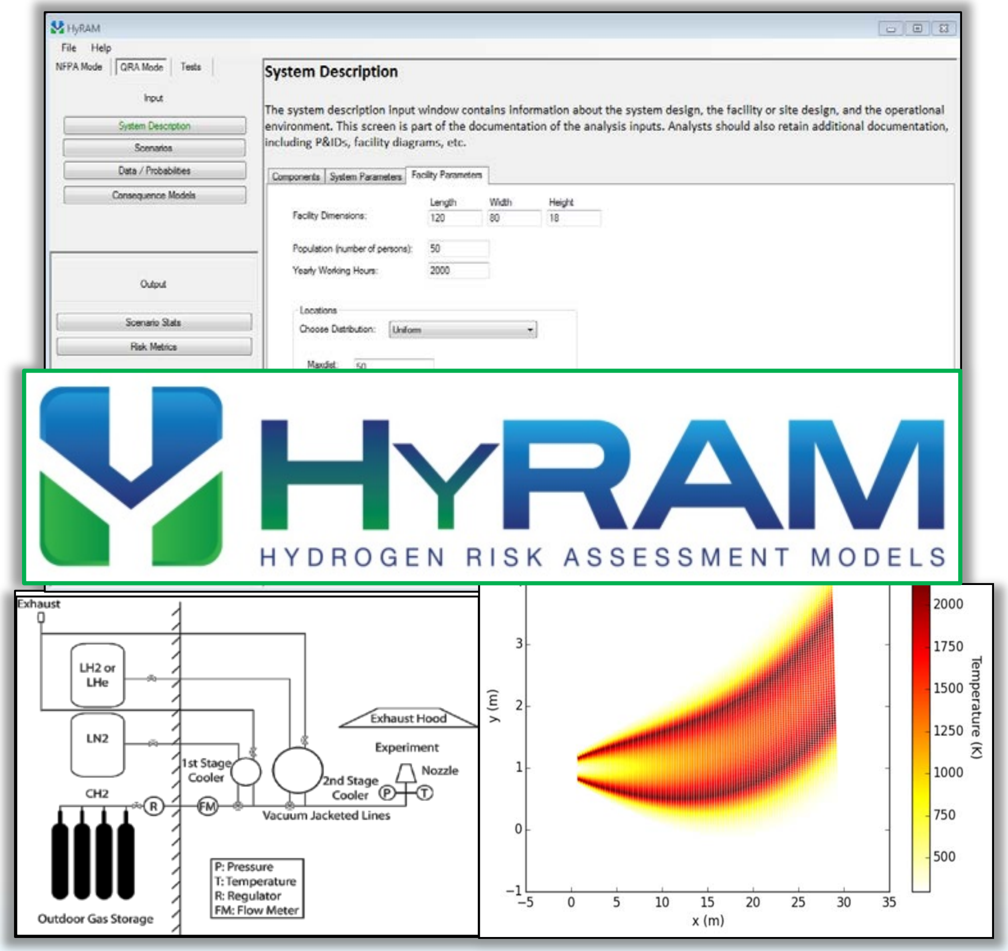
- **Alternative Methods**
  - Agreement between real world station owner and hydrogen supplier is not reached in time to develop performance-based design option prior to October 2015 funding subsidy
  - Local AHJ acceptance of a performance based design of a hydrogen refueling station
- **Science-based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

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

NFPA 2 Performance-Based Design: Hazardous Materials Scenarios

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

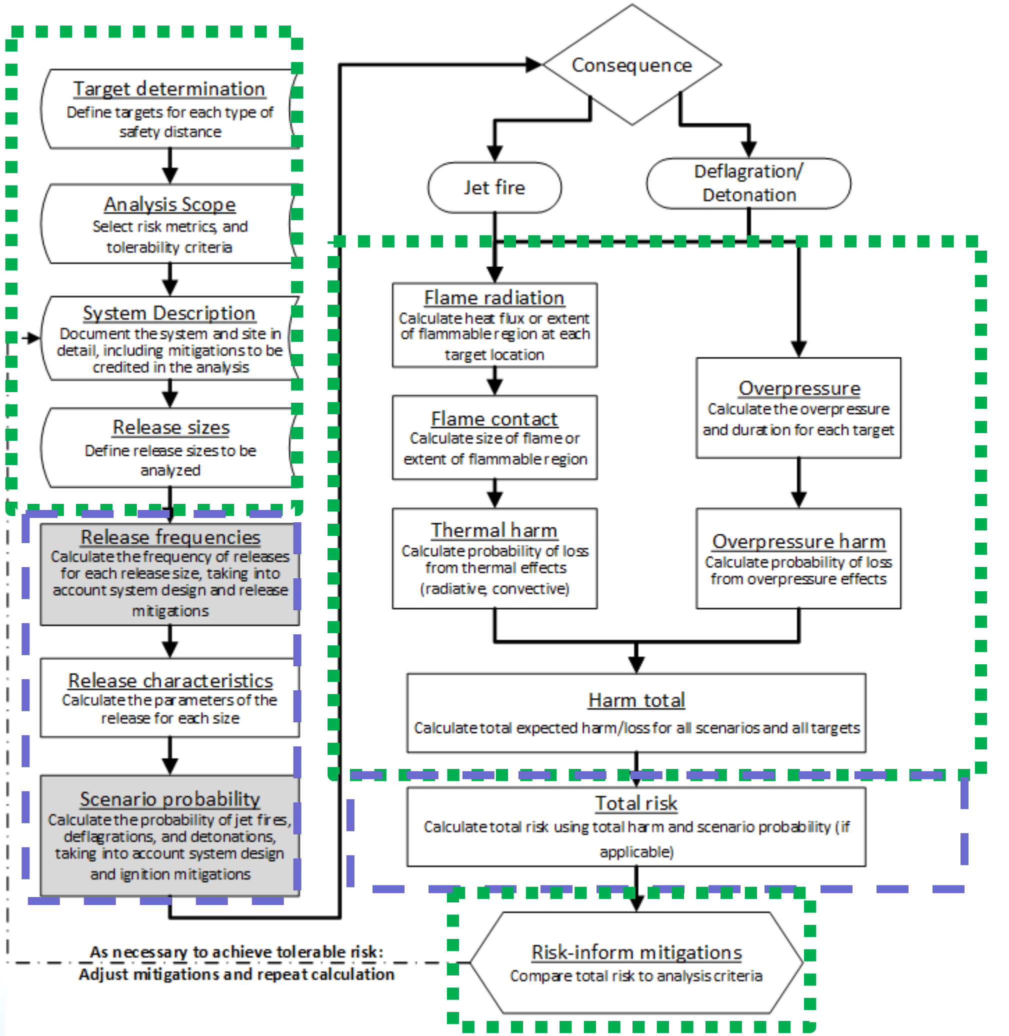
NFPA 2 Performance-Based Design:
Scenarios which do not apply to an outdoor fueling station

	Egress System	Max Occupant Load with Blocked Exit	Construction in area of building with suppression system out of service
Scenario Description	5.4.2: Design for life safety affecting the egress system	5.4.5.1: Maximum occupant load is in the assembly building and the principal exit/entrance is blocked	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.
Discussion of Applicability	No egress system since fueling station is outdoors	No assembly occupancies in the vicinity and no exits to block	No partially-occupied buildings with suppression system out of service to analyze

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



REV.	DESCRIPTION	DATE	BY
V1	First draft of this flowchart	10/6/14	KMG
V2	Corrected to release size shape, chars	10/21/14	KMG
V3	Deflag to flamerad path; feedback loop	11/11/14	KMG
V4	Improved mitigation language	12/11/14	KMG