Enabling Hydrogen Infrastructure Through Science-based Codes and Standards

PI: Chris LaFleur

Team: Myra Blaylock, Andrew Clark, Katrina Groth, Ethan Hecht, Terry Johnson, Alice Muna

Sandia National Laboratories

Livermore, CA and Albuquerque, NM

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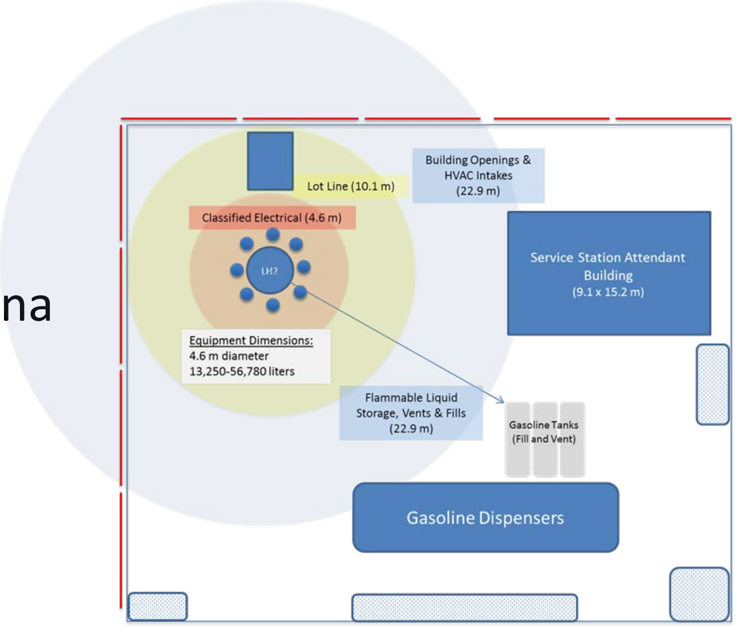

Project ID SCS025

2016 DOE Hydrogen and Fuel Cells Annual Merit Review

SAND2016-4017 PE

U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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Overview

Timeline

- Project start date: Oct. 2003
- Project end date: Sept. 2016*

*Project continuation and direction determined annually by DOE

Barriers

F. 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

- FY15 DOE Funding: $220K
- Planned FY16 DOE Funding: $230K
- Total DOE Funds Received to Date: $23M

(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 HGV4.3 and 4.9, ISO TC197

International engagement:
HySafe, HyIndoor, IEA HIA Task 31

Relevance

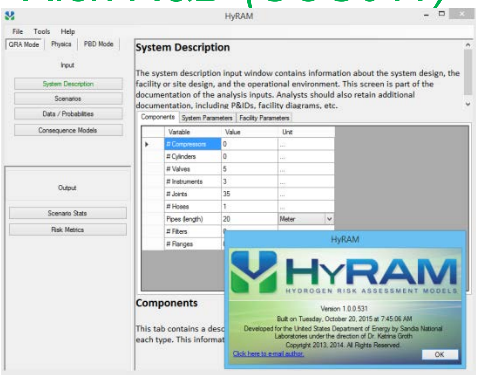
Objective: Enable the growth of hydrogen infrastructure through science and engineering-based Codes and Standards

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

Barrier from 2013 SCS MYRDD	SNL Impact
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	Develop and demonstrate risk-equivalent station design
K. No Consistent Codification Plan and Process for Synchronization of R&D and Code Development	Apply H2-specific QRA tools & methods to support code improvement and to enable risk-equivalent code compliance option

Project approach: *Coordinated activities* to enable consistent, rigorous, and accepted safety analysis

Risk R&D (SCS011)



Develop integrated methods and algorithms

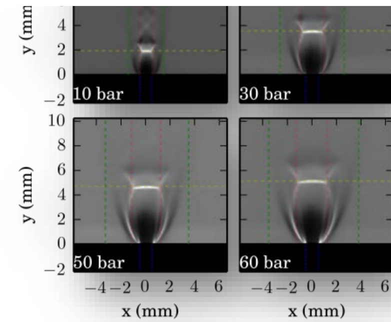
for enabling consistent, traceable and rigorous QRA

Application in C&S (SCS025)

Apply QRA & behavior models to real problems

in hydrogen infrastructure and emerging technology

Behavior R&D (SCS010)



Develop and validate scientific models

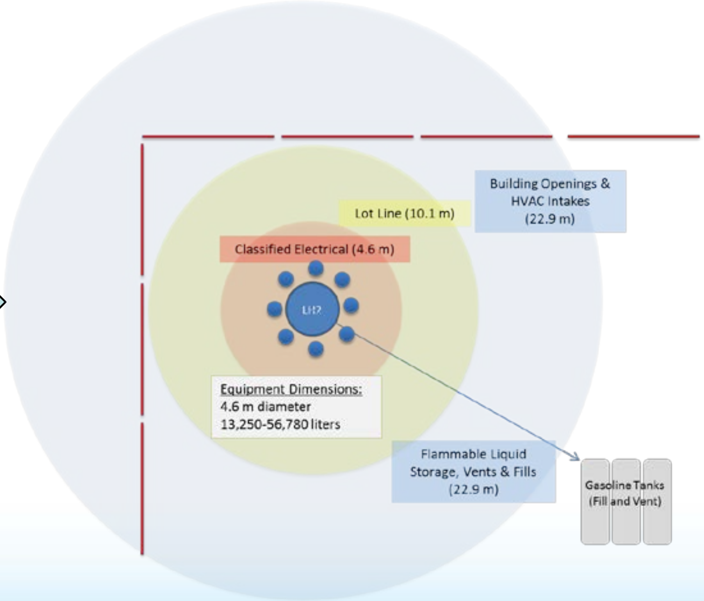
to accurately predict hazards and harm from liquid releases, flames, etc.

Enabling methods, data, tools for H_2 safety & RCS

Approach: Enabling Hydrogen Infrastructure

Alternative Methods for Code Compliant Hydrogen Infrastructure

Science-based Code Revisions to Address Critical Limitations to Station Implementation



Supporting advanced technology implementation in the short and long term

Approach / FY15-16 Milestones

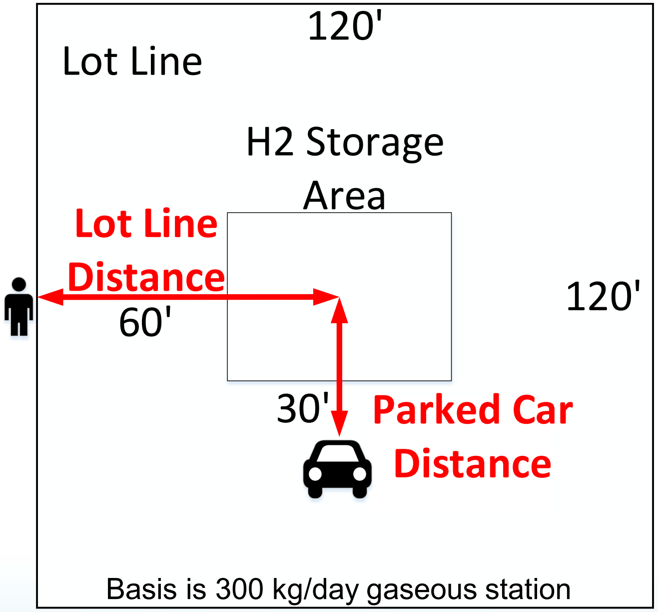
Alternative Methods for Code Compliance for Refueling Station	Completion date or status
• **Calculate Benchmark Risk Value**	
• Publish Final Template of performance-based design (PBD) • Developed Benchmark Value Report	June 2015 September 2015
• **Demonstrate Performance-based Design for a Real-world station**	
• Station selection – • AHJ socialization and education • Develop PBD design, justification and station permitting	Several Considered Multiple Meetings Conducted Ongoing (75%)
Science-based Code Improvements	
• **Update Science Basis of Liquid Separation Distances in NFPA 2/55**	
• Analyze Scenarios of Concern for Basis of Code Revision • Characterize Modeling Parameters for Liquid Release Characterization • Develop Risk-Informed Separation Distance Revision Proposals to Code	June 2015 July 2015 Drafted Revised Annex
• **Update Gaseous Separation Distances Based on Revised Risk Criteria**	
• Develop Scientific Justification for Risk Criteria Revision • Calculate Revised Distances	December 2015 January 2016
• **Synchronize with International Standards**	
• ISO TC 197 Working Group • CSA 4.3 and 4.9	TIR Drafted Published March 2016

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 2/55 subcommittee to revise based on risk-informed science of LH2 release behavior
- **Alternative Methods for Code Compliance** - In the meantime, this effort is exploring a path forward for short term deviation from separation distances for LH2

Accomplishment: Benchmark Risk Value for Gaseous Hydrogen Station

- Developed draft report which assessed the risk of an H2FIRST reference station using QRA and consequence-only analysis
- Will be integrated into H2FIRST as an appendix (SAND2015-2660R)



Cases	Safety Calculation	Baseline Result
Lot Line Separation Distance	Perform **QRA** on H2First reference station to determine Potential Loss of Life (PLL) metric at 60 ft.	The PLL for this scenario is equal to **2.18E-05** fatalities/system-year.
Parked Vehicle Separation Distance	Perform **consequence** calculation to determine jet flame temperature at 30 ft.	The temperature at 30 ft. is close to **ambient temperature**.

Demonstrating the calculation of benchmark risk values can be used for alternate methods of code compliance.

Progress: Real World Application of Alternate Means

- Goal: Establish alternate means as a viable station permitting option with our industry partner, Linde
- Progress:
  - Developing compliance substantiation for the Linde compressor enclosure
  - 2016 NFPA 2 Hydrogen Equipment Enclosure Issues
    - 2 hour ‘wall’ separation between H2 storage and compressor/electrical area
    - NFPA 68 compliance (meets European standards)
  - Approach is to evaluate multiple leak scenarios to demonstrate that the intent of the prescriptive requirements are met and the alternate design incorporates measures to ensure equivalent system safety

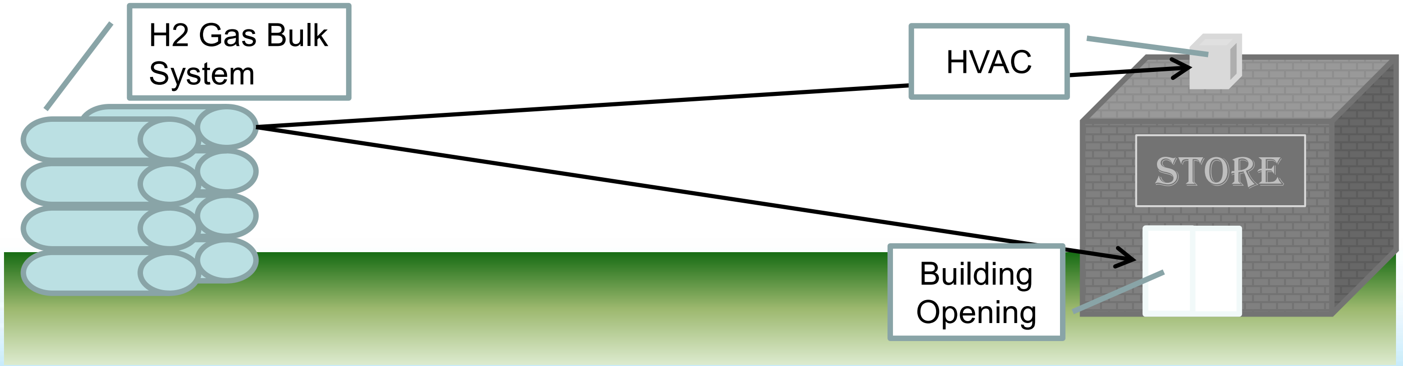
Demonstrating alternate means of compliance increases options for industry in siting hydrogen fueling stations and overall confidence in the performance-based approach for station design

Progress: Science-Based Gaseous Separation Distances

- Goal: Update NFPA 55/2 gaseous separation distances using scientific justification for risk criteria
- Progress:
  - Three updates were evaluated:
    - Unignited jet concentration from 4% to 8%
    - Heat Flux level from 1.6 kW/m^2 to 4.7 kW/m^2
    - Leak area from 3% to 1%
    - Added safety factor of 1.5

Exposures	Code Version	Separation Distance			
		>0.10 to 1.72 MPa	>1.72 to 20.68 MPa	>20.68 to 51.71 MPa	>51.71 to 103.43 MPa
Group 1 Exposures	2016	12 m	14 m	9 m	10 m
	2019	**5 m**	**6 m**	**4 m**	**5 m**
Group 2 Exposures	2016	6 m	7 m	4 m	5 m
	2019	**5 m**	**6 m**	**3 m**	**4 m**
Group 3 Exposures	2016	5 m	6 m	4 m	4 m
	2019	**4 m**	**5 m**	**3 m**	**4 m**

2016: 10 m for 70 MPa storage



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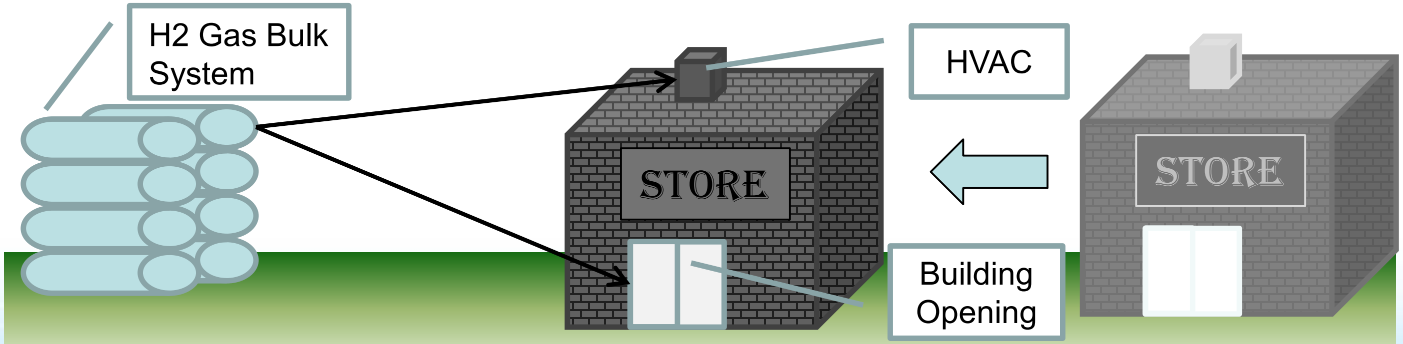


Risk-based code requirements based on proposed risk threshold revisions enable more sites to readily accept hydrogen infrastructure

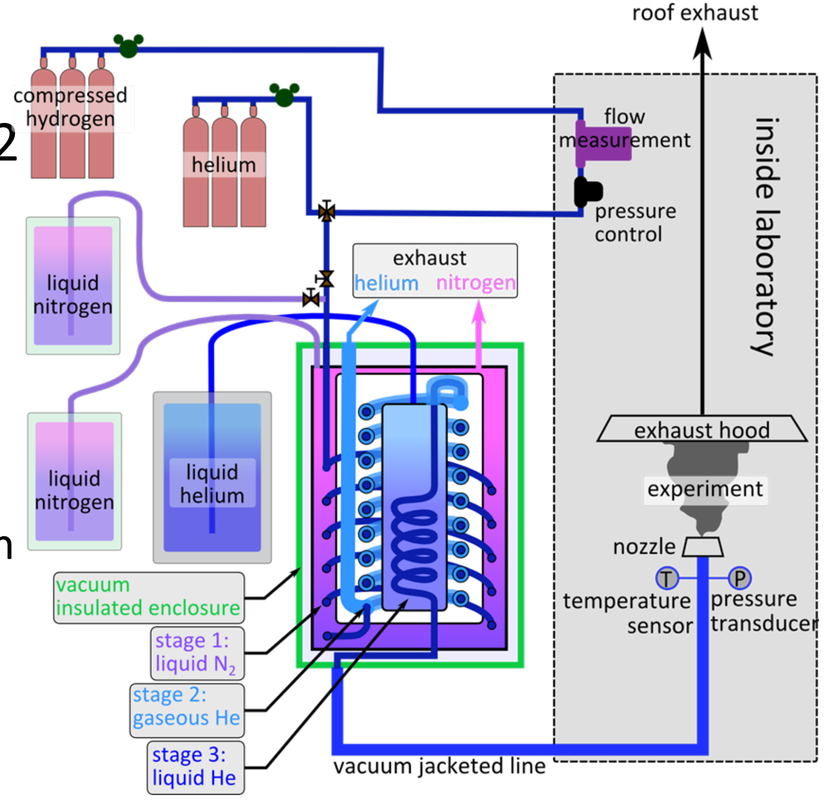
Progress: Science-Based Prescriptive Requirement Revisions LH2

- Goal: Use QRA tools and methods to revise bulk liquid hydrogen system separation distances in NFPA 55/NFPA 2
- Progress:
  - The NFPA 55/2 hydrogen storage task group performed a risk analysis on a representative bulk liquefied hydrogen storage system and determined nine release scenarios with the highest risk
    - Six of the highest-risk scenarios are during liquid hydrogen transfer operations from a tanker truck to the bulk LH2 storage tank
    - Three scenarios are during normal system operations
  - Determined model inputs and risk criteria for the nine scenarios

Results of the risk analysis on the bulk liquefied hydrogen storage system will be fed into liquid hydrogen models

Progress: LH2 Informing Science-based Code Revisions

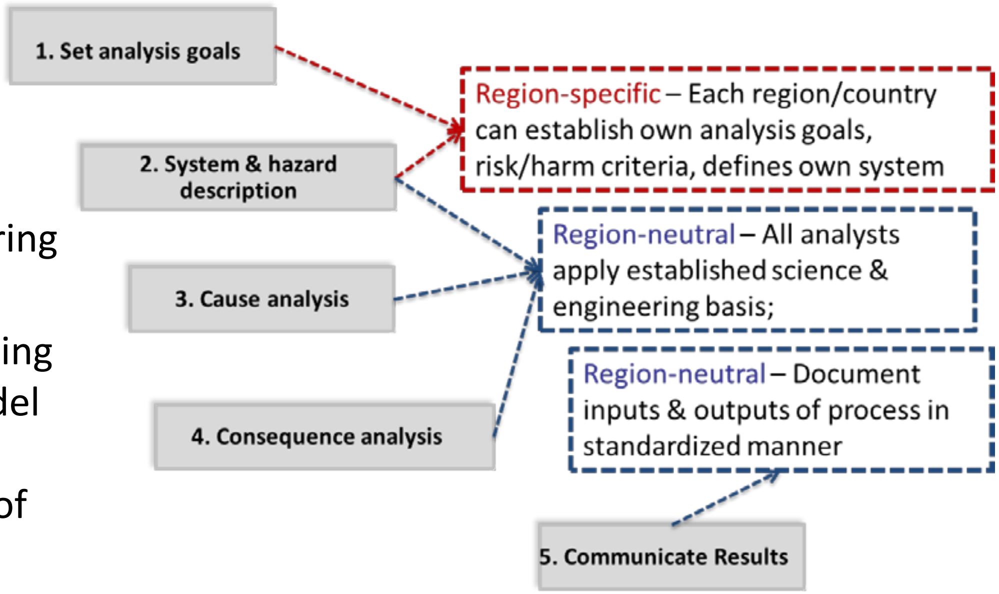
- Goal: Use QRA tools and methods to revise bulk liquid hydrogen system separation distances in NFPA 55/NFPA 2
- Progress:
  - Multi-Party CRADA signed with Bki and Fire Protection Research Foundation to enable industry participation in support of LH2 model validation experimentation efforts
  - Providing technical leadership and hydrogen release behavior models to incorporate current science and technology information to risk-inform code requirements
  - Details given in SCS-010 AMR presentation



Validated LH2 release model will be used to risk-inform the revised LH2 bulk separation

Accomplishment: International recognition of HyRAM via incorporation into ISO DTR-19880-1

- Co-lead the safety methodology sub-team
- Authored Chapter 4 (Risk management)
- Defined common terminology for types of safety distances and framework for comparing safety distances
- Defined common methodology for developing specific requirements with flexibility in model choices (Encompasses options for QRA, consequence modeling, and combinations of both.)
  - Countries/regions follow the same general method, and document country-specific assumptions and model choices; HyRAM enables rapid comparison of the impact of assumptions, data, & modeling choices



- Developed template for documenting the region-specific examples (to become Annex A)
- ISO DTR-19880-1 accepted via voting countries Oct 2015

HyRAM enables a science-based safety methodology for US and international codes through the use of common QRA methods

Accomplishment: CSA Standards Improvements

HGV 4.3 - Establishes the test method, criteria, and apparatus to evaluate a hydrogen fueling station

- Feedback to committee from HyStEP Device (H2FIRST Project) development and testing
- Standard completed and submitted for publication

HGV 4.9 - Establishes safety requirements for the design, manufacture and testing of gaseous hydrogen compressor packages used in fueling station service

- Standard completed and submitted for publication

Enable hydrogen vehicle implementation by providing expertise to develop and improve standards governing

Response to Previous Year Reviewers' Comments

2015 AMR Reviewer Comment	Response
"A more clearly articulated and coordinated approach with related industry and laboratory efforts regarding messaging with AHJs would improve the project."	Collaboration efforts with both PNNL and NREL include targeting AHJ and local authority education and messaging.
"Coordinated plan for promoting acceptance of the resulting risk-informed methodologies into the codes and standards"	The risk-informed methodologies have already been incorporated into the NFPA process, formally through the SFPE's *Guidance Document for Incorporating Risk Concepts into NFPA Codes and Standards*. Also, the previous revisions to the bulk gaseous hydrogen storage requirements established precedence in this regard.
"For this critical technical work to be useful in achieving the desired adoption of risk-informed alternative compliance methodologies, a well-thought-out plan for vetting, educating, resolving concerns, etc. should be included."	Our strategy so far focuses on establishing a precedence of a real world station adoption of this compliance option. In this way, our education efforts are more precise and effective.

Collaborations

Relationship	Partner	FY 15 - FY16 Role
CRADA	**Industry:** Linde Group, Industrial gas supplier	CRADA for In-kind support, data exchange for QRA tool and QRA demonstration activities, real world station for alternate means permitting
CRADA	**Industry**: BKi (Manager of the California Fuel Cell Partnership)	Develop industry stakeholders in support of LH2 Behavior Characterization
CRADA	**Code Industry**: Fire Protection Research Foundation	Lead stakeholder oversight panel and enable link to NFPA code process
Collaborator	**International :** HySafe	Technical exchanges, ISO
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
CaFCP, ASME
DOE Hydrogen Safety Panel, DOT FRA
PNNL, NREL
AIST (Japan), HyIndoor (EU)

Remaining Challenges and Barriers

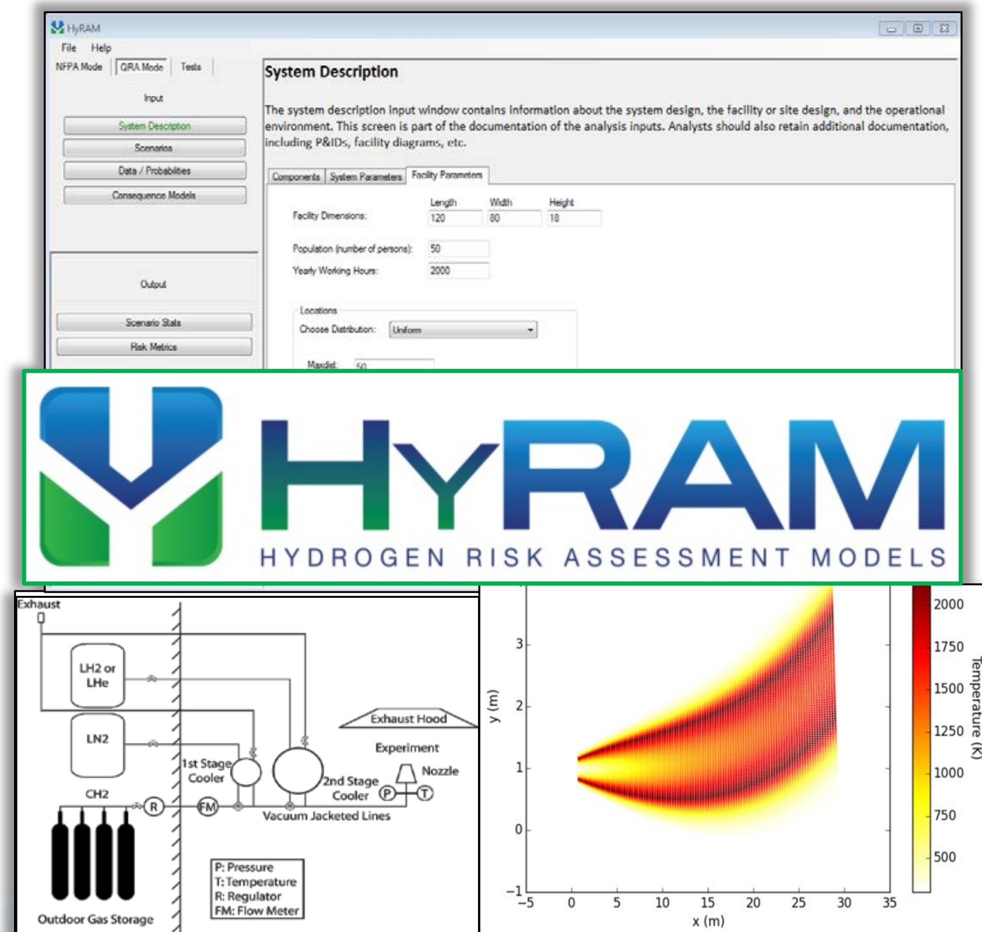
- **Alternative Methods**
  - Agreements between real world station owner and hydrogen supplier are extremely challenging and have hindered the opportunity to complete a permit application and substantiation
  - Local AHJ acceptance of a performance based design of a hydrogen refueling station
- **Science-based Code Improvements**
  - Insufficient industry participation as stakeholders to complete cold plume release validation experiments in FY17 and FY18
  - 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 FY16
  - **Alternative Methods**: Identify opportunity for permitting of real world station
  - **Science-based Code Improvements**: Analyze LH2 scenarios with initial cold plume model to establish timeline for proposal of revisions to separation distances
- FY17
  - **Alternative Methods:** Develop opportunity for other hydrogen applications where an alternative solution is needed
  - **Science-based Code Improvements** : Refine characterization of LH2 releases with validated cold plume release and ignition model to provide sound scientific basis for revised separation distances in NFPA 2/55.
- Out-years
  - Continue harmonization 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

- **Benchmark Risk:**
  - 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
- **Alternate Means of Code Compliance**
  - 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: Harmonization with international codes
  - By: Active technical leadership on working groups revising risk-based methodology

Technical Back-Up Slides

Details of LH2 Prescriptive Code Revision Scenario Selection and Prioritization

- CGA P-28 *OSHA Process Safety Management and EPA Risk Management Plan Guidance Document for Bulk Liquid Hydrogen Systems* was used as a basis for typical LH2 system definition and HAZOP scenario identification
- Each scenario was reviewed and assigned an Even Hazard and Hazard Severity value.
- Based on these values, the scenario was given a risk ranking which was used to prioritize the scenario

Event Likelihood Classification

Level	Annual Probability	Probability Description
1	Frequent > 1.0	Expected to occur once per year or more frequently.
2	Reasonably probable 1.0 to 0.1	Expected to occur once per 10 years.
3	Occasional 0.01 to 0.1	Expected to occur once per 100 years.
4	Remote 0.001 to 0.01	Expected to occur once per 1000 years.
5	Extremely remote 0.0001 to 0.001	Expected to occur once per 10,000 years.
6	Improbable < 0.0001	Expected to occur less than once per 10,000 years. Extremely unlikely to occur.

Hazard Severity Classification

Level	Description	Potential Consequences
1	Catastrophic	May cause fatality to non-associated members of the public.
2	Critical	May cause severe injury to non-associated members of the public, fatality or serious injury to works of the public, fatality or serious injury to workers of persons conducting business at a refueling site or significant damage to equipment/facilities.
3	Marginal	May cause minor injury, or minor system damage.
4	Negligible	Will not result in injury or system damage.

Risk Ranking:

		Likelihood					
Severity		1	2	3	4	5	6
	1	1	1	1	2	3	4
	2	1	1	2	3	3	4
	3	2	2	3	3	4	4
	4	4	4	4	4	4	4

1: High Risk
2: Moderate Risk
3: Low Risk
4: Routine Risk

LH2 Prioritized Scenarios to be Used for Separation Distance Revision

	HAZOP Number and Description	
Release scenarios during liquid transfer to bulk storage tank	1.18	High flow of gaseous hydrogen from trailer vent stack due to venting excess pressure after LH2 transfer
	1.19	Normal flow from trailer vent stack due to venting excess pressure after LH2 transfer
	1.6	High flow from line rupture, valve or component failure during transfer process
	1.4	High temperature due to external fire causes high flow venting through tank vent stack
	1.8	Reverse flow during transfer process caused by human error and pressure mismanagement
	1.16	Loss of containment from external impacts, consider all causes

	HAZOP Number and Description	
Release scenarios during normal system operation	4.15	Loss of containment from pipe leading from tank to vaporizer or vaporizer itself caused by thermal cycles or ice falling from vaporizers
	6.15	Misdirected flow caused by operator error resulting in large low level release of cold gaseous hydrogen through bottom drain valve of vent stack during normal tank venting process
	2.1	High pressure because of a leak in inner vessel allowing hydrogen into the vacuum area

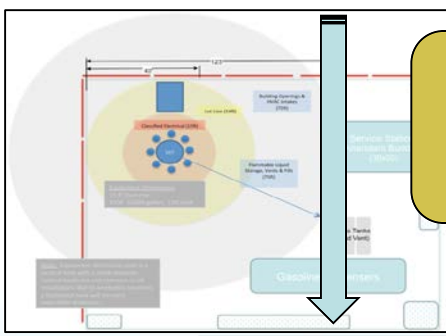
Approach: Application of QRA to Performance-Based Design

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