

## VIII.10 Enabling Hydrogen Infrastructure Through Science-Based Codes and Standards

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### Contribution to Achievement of DOE Safety, Codes & Standards Milestones

This project will contribute to achievement of the following DOE milestones from the Hydrogen Safety, Codes and Standards section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

- Milestone 2.19: Validate inherently safe design for hydrogen fueling infrastructure. (4Q, 2019)
- Milestone 4.7: Complete risk mitigation analysis for advanced transportation infrastructure systems. (1Q, 2015)
- Milestone 4.8: Revision of NFPA 2 to incorporate advanced fueling storage systems and specific requirements for infrastructure elements such as garages and vehicle maintenance facilities. (3Q, 2016)

### Overall Objectives

- Enable the growth of hydrogen infrastructure through science and engineering-based codes and standards.
- Enable industry-led codes and standards revision and safety analyses by providing a strong science and engineering basis code improvements.
- Eliminate barriers to deployment of hydrogen fuel cell technologies through scientific leadership in codes and standards development efforts.

### Fiscal Year (FY) 2016 Objectives

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

### Technical Barriers

This project addresses the following technical barriers from the Hydrogen Safety, Codes and Standards section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

- (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

### FY 2016 Accomplishments

- Developed a benchmark risk value for a Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) gaseous hydrogen reference refueling station which demonstrates the use of quantitative risk assessment (QRA) methods, promotes safety through the use of performance criteria rather than explicit prescriptive requirements, and enables a risk-informed compliance option.
- Calculated revised bulk gaseous separation distances using revised risk criteria for adoption by the National Fire Protection Association (NFPA) 2/55 technical committees which will enable more sites to readily accept hydrogen infrastructure.
- Incorporated QRA into the International Organization for Standardization Technical Report 19880-1 Gaseous Hydrogen-Fueling Stations and provided leadership and support for integrating safety assessments into the standard.



### INTRODUCTION

DOE Fuel Cell Technologies Office has identified safety, codes, and standards as a critical barrier to the deployment of hydrogen, with key barriers related to the availability and implementation of technical information in the development of regulations, codes and standards. This project provides the technical basis for assessing the safety of hydrogen fuel cell

systems and infrastructure using QRA and physics-based models of hydrogen behavior. The risk and behavior tools are used to support both alternate methods of code compliant hydrogen infrastructure as well as direct support of code committees in support of science-based revisions that address critical limitations to refueling station implementation. This project provides the scientific basis to ensure that code requirements are consistent, logical, and defensible.

## APPROACH

State-of-the-art integrated hydrogen behavior and QRA models are applied to relevant technologies and systems to provide insight into the risk level and risk mitigation strategies with the aim of enabling the deployment of fuel cell technologies through revision of hydrogen safety, codes, and standards. In the short term focus of providing alternative methods for code compliance, a benchmark risk value for an H2FIRST system design utilizing the previously developed template is calculated in order to provide hydrogen information and risk analysis methods to authorities having jurisdiction. This effort will enable hydrogen refueling stations that are unable to explicitly meet prescription code requirements to utilize alternate means allowed by the current code. Implementing the template at a real world hydrogen station planned in California will provide precedence for a performance-based design and will allow the cost and schedule for developing this type of station design to be optimized.

Towards the longer term goal of achieving science-based revisions of codes and standards, a review and revision of the risk-informed code requirements for bulk gaseous hydrogen storage will enable behavior models and technology not available during the 2009 revision to be incorporated in to the risk criteria used to determine these requirements. The bulk liquid hydrogen storage code requirements will also be revised following a similar process once the cold plume release model is validated.

## RESULTS

### Calculate Benchmark Risk Value

NFPA 2, Hydrogen Technologies Code, allows for the use of alternate means of code compliance, including performance-based design, for hydrogen facilities as a means of complying with the code without strict adherence to the prescriptive code requirements. While the Hydrogen Risk Assessment Model (HyRAM) can be used as a means of evaluating the risk of alternate designs, it can also be used to quantitatively evaluate risks associated with alternate means of code compliance. The establishment and demonstration of alternate means will directly increase the availability of locations for hydrogen fueling stations, reduce the effort required by industry to use alternate approaches and lay the

groundwork for similar QRA-backed design processes for other alternative fuels.

The HyRAM software was used to calculate risks of an outdoor, gaseous hydrogen fueling station that is fully compliant with NFPA 2 requirements and is accessible to the public in order to establish benchmark risk values for these metrics for a specific station configuration. Two methods for analyzing a hydrogen fueling station were demonstrated: QRA and consequence-only analysis. The two methods were implemented to provide detailed insight into different aspects of station risk. The benchmark report provided a single example of each approach, applied to the H2FIRST reference station design for a gaseous hydrogen fueling station with a 300 kg/d capacity [1]. The benchmark values calculated are presented in Table 1.

**TABLE 1.** Summary of Risk Calculations for Prescribed Distances

Cases	Safety Calculation	Baseline Result
<b>Lot Line Separation Distance</b>	Perform <b>QRA</b> on H2FIRST reference station to determine potential loss of life metric at 60 ft	The potential loss of life for this scenario is equal to <b><math>2.18 \times 10^{-5}</math></b> fatalities/system-year.
<b>Parked Vehicle Separation Distance</b>	Perform <b>consequence</b> calculation to determine jet flame temperature at 30 ft	The temperature at 30 ft is close to <b>ambient temperature</b> .

### Update Science Basis of Bulk Hydrogen Separation Distances

The bulk separation distances in NFPA 2/55 are categorized into three groups depending on the hazard scenario and harm criteria used to determine the separation distances. A task group was formed for the purposes of revising the risk-informed distances in the tables. The harm criteria for the bulk gaseous hydrogen analysis performed in 2009 were revisited and revised by the task group. In order to determine the impact of these changes on the distance requirements, we calculated the revised distances for bulk gaseous storage. The resulting reductions in the separations distances are shown in Table 2 which will be proposed for adoption in the 2019 revision to NFPA 2/55.

The task group also worked to apply the risk-informed process to the bulk liquefied hydrogen storage separation distances using the same process as the gaseous storage. We performed a risk prioritization on a published representative liquefied hydrogen system described in the Risk Management Plan Guidance Document for Bulk Liquid Hydrogen Systems 2009 (CGA P-28) utilizing the hazard and operability study in that document. The resulting high risk release scenarios include those that occur during liquid hydrogen transfer operations from a tanker truck to the bulk liquid hydrogen storage tank as well as during normal system operations. These scenarios will be modeled with Sandia's hydrogen

**TABLE 2.** Draft Updated Values to 2016 NFPA 2 and NFPA 55 Tables with 1.5 Safety Factor

Exposures		Separation Distance			
		>0.10 to 1.7 MPa (>15 to 250 psig)	>1.7 to 20.7 MPa (>250 to 3,000 psig)	>20.7 to 51.7 MPa (>3,000 to 7,500 psig)	51.7 to 103.4 MPa (7,500 to 15,000 psig)
Group 1	Existing	12 m (40 ft)	14 m (46 ft)	9 m (29 ft)	10 m (34 ft)
	Proposed New	<b>5 m (16 ft)</b>	<b>6 m (20 ft)</b>	<b>4 m (13 ft)</b>	<b>5 m (16 ft)</b>
Group 2	Existing	6 m (20 ft)	7 m (24 ft)	4 m (13 ft)	5 m (16 ft)
	Proposed New	<b>5 m (16 ft)</b>	<b>6 m (20 ft)</b>	<b>3 m (10 ft)</b>	<b>4 m (13 ft)</b>
Group 3	Existing	5 m (17 ft)	6 m (19 ft)	4 m (12 ft)	4 m (14 ft)
	Proposed New	4 m (13 ft)	5 m (16 ft)	3 m (10 ft)	4 m (13 ft)

release model to help revise the distances in the next code cycle so that they are risk-informed and based on sound science and physics for the behavior of release hydrogen.

**Codes and Standards Participation**

- CSA Hydrogen Gas Vehicle 4.9 and 4.3 – Hydrogen fueling station guidelines have been reviewed by industry and comments received. The CSA standards were both issued after all were resolved and dispositioned.
- Hydrogen Safety Panel – Sandia participated in several hydrogen safety plan reviews for innovative industrial hydrogen implementations.
- International Organization for Standardization Technical Report 19880-1 – Sandia led the incorporation of QRA and safety assessment methodologies into the standard. The safety assessment methodology in TS-19980-1, which is based on the HyRAM methodology, allows countries to follow a common methodology for performing safety assessment with county- or region-specific assumptions and modeling choices. HyRAM was used to support the development of regional examples contained in Annex A.
- NFPA 2 – Sandia is providing ongoing technical leadership in the Bulk Hydrogen Storage Task Group of NFPA 2 Hydrogen Technologies Code. The task group began work on revision and update of the prescriptive requirements for both liquefied and gaseous hydrogen separation distances for the next revision cycle of the code.

**CONCLUSIONS AND FUTURE DIRECTIONS**

- The template for implementing the performance-based approach will be used to demonstrate a credible alternate means of code compliance as part of the permitting process to demonstrate acceptance of the approach by an authority having jurisdiction in a real-world station.

- Extend performance-based design template to other hydrogen application where an alternative solution is needed (future).
- The prioritized liquid hydrogen release scenarios will be analyzed with the validated cold plume release model to characterize the unintended release of liquid–vapor mixed-phase hydrogen releases to revise bulk hydrogen storage code requirements.
  - Identify research gaps in evaluating and prioritizing mitigation features in hydrogen systems (future).
  - Incorporate recent research and technological advancements into further revisions to the bulk gaseous storage requirements (future).

**FY 2016 PUBLICATIONS/PRESENTATIONS**

1. A.C. LaFleur, A.B. Muna, and K.M. Groth. *Fire Protection Engineering Design Brief Template: Hydrogen Refueling Station*, SAND2015-4500, Sandia National Laboratories, June 2015.
2. LaFleur, A.C., “Enabling Hydrogen Infrastructure Through Science-based Codes and Standards.” Presented at the 2015 DOE Hydrogen and Fuel Cells Program and Vehicle Technologies Office Annual Merit Review and Peer Evaluation Meeting, June 2015.
3. A.C. LaFleur, A.B. Muna and K.M. Groth. “Application of Quantitative Risk Assessment for Performance-Based Permitting of Hydrogen Fueling Stations.” In Proceedings of the International Conference on Hydrogen Safety (ICHS 2015), Yokohama, Japan, October 19–21, 2015.
4. T. Skjold, D. Siccama, H. Hisken, A. Brambilla, P. Middha, K.M. Groth and A.C. LaFleur. “3D Risk management for hydrogen installations (Hy3DRM).” In Proceedings of the International Conference on Hydrogen Safety (ICHS 2015), Yokohama, Japan, October 19–21, 2015.
5. J. Schneider, G. Dang-Nhu, N. Hart, and K. Groth. “ISO 19880-1, Hydrogen Fueling Station and Vehicle Interface Safety Guideline.” In Proceedings of the International Conference on Hydrogen Safety (ICHS 2015), Yokohama, Japan, October 19–21, 2015.
6. C. San Marchi, E.S. Hecht, I.W. Ekoto, K.M. Groth, C. LaFleur, B.P. Somerday, R. Mukundan, and T. Rockward. “Advances

in research and development to enhance the scientific basis for hydrogen regulations, codes, and standards.” In Proceedings of the International Conference on Hydrogen Safety (ICHS 2015), Yokohama, Japan, October 19–21, 2015.

**7.** K.M. Groth. “Application of quantitative risk assessment for performance-based permitting of hydrogen fueling stations.” Presented at the International Conference on Hydrogen Safety (ICHS 2015), Yokohama, Japan, October 21, 2015.

**8.** K. Groth. “Safety assessment & mitigation sub-team update.” Presented at ISO TC197 WG24 meeting, Tokyo, Japan, October 27, 2015.

**9.** C. San Marchi, E.S. Hecht, I.W. Ekoto, K.M. Groth, C. LaFleur, B.P. Somerday, R. Mukundan, T. Rockward, J. Keller & C.W. James. “Overview of the DOE hydrogen safety, codes and standards program, part 3: Advances in Research and Development to Enhance the Scientific Basis for Hydrogen regulations, Codes and Standards.” Submitted for publication in International Journal of Hydrogen Energy, (Submitted February 2016).

**10.** K. Groth. “Safety assessment & mitigation sub-team update,” Presented at ISO TC197 WG24, Munich, Germany, 22 June 2016.

**11.** C. LaFleur, A.B. Muna and K.M. Groth. “Application of Quantitative Risk Assessment for Performance-Based Permitting of Hydrogen Fueling Stations.” Accepted for publication in International Journal of Hydrogen Energy (Accepted July 2016).

**12.** A. Muna, C. LaFleur, M. Gresho, C. Rivkin, “*Siting Bulk Hydrogen Storage Systems: Advances in Risk-Informed Siting Procedures in NFPA Codes*,” American Institute of Chemical Engineers, 12th Global Congress on Process Safety, paper submitted to be published in the proceedings of the April 2016 meeting.

## REFERENCES

**1.** Pratt, J., Terlip, D., Ainscough, C., H2FIRST– Reference Station Design Project Deliverable 2-2, SAND2015-2660, Sandia National Laboratories and National Renewable Energy Laboratory, 2014.