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

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Project Start Date: October 1, 2003
Project End Date: Project continuation and direction determined annually by DOE

Overall Objectives

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

Fiscal Year (FY) 2017 Objectives

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

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.

(H) Insufficient technical data to revise standards

(A) Insufficient Synchronization of National Codes and Standards

(K) No Consistent Codification Plan and Process for Synchronization of R&D and Code Development

(A) Usage and Access Restrictions

Contribution to Achievement of DOE Safety, Codes and Standards Milestones

This project will contribute to achievement of the following DOE milestones from the 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 and storage systems and specific requirements for infrastructure elements such as garages and vehicle maintenance facilities. (3Q, 2016)

FY 2017 Accomplishments

- Performed calculations and risk analysis for 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.
- Developed risk analysis framework and identified scenarios of concern for tunnel access for hydrogen fuel cell electric vehicles.
- Completed computational fluid dynamics (CFD) and heat transfer models to evaluate hydrogen fire impact on steel structure and concrete in passenger vehicle tunnels.

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INTRODUCTION

The 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 quantitative risk assessment and physics-based models of

hydrogen behavior. The risk and behavior tools are used to support alternate methods of code-compliant hydrogen infrastructure and directly support code committees in incorporating 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 quantitative risk assessment 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, 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 into the risk criteria used to determine these requirements. The bulk liquid hydrogen storage code requirements will also be revised following a similar review. For northeastern United States tunnel access, a risk framework and scenarios of concern will be developed and analyzed to address the concerns of local authorities having jurisdiction.

RESULTS

Science-based Hydrogen Storage Code Improvements

The bulk hydrogen storage 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. The revised distances for bulk gaseous storage, based on Sandia's risk calculations for the revised risk and harm criteria, were proposed in the first draft stage of the 2020 NFPA code revision cycle. The resulting reductions in the 2016 separation distances are shown in Table 1. The Technical Committee approved these revisions for adoption in the 2020 edition of NFPA 2/55.

The NFPA 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. The prioritized hydrogen 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 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 released hydrogen.

Evaluation of Existing Tunnel for Fuel Cell Electric Vehicle Safety

Several authorities in the Northeast expressed concerns about allowing fuel cell electric vehicle access to important tunnels in their metro areas (New York City, Baltimore, and Boston). Our goal is to provide the scientific modeling and risk analysis for these authorities having jurisdiction and emergency responders to address their concerns regarding fuel cell electric vehicles. We participated in several face-to-face meetings with the authorities having jurisdiction in order to collect information about the nature of their concerns. We developed a risk framework in the form of an event sequence diagram to capture the possible scenarios and analyzed data to assign probabilities, based on frequencies of tunnel incidents, for each branch line. We conducted an initial analysis to compare anticipated hydrogen release scenarios with the NFPA 502 (National Fire Protection Association, 2016) [1] requirements for tunnel fires. We subsequently performed a computational fluid dynamics modeling analysis to address concerns for a specific incident where an overturned vehicle releases hydrogen through its thermal

TABLE 1. Technical Committee Approved Updated Values to NFPA 2 and NFPA 55 Separation Distance Tables

Exposures >0.10 to 1.7 MPa (>15 to 250 psig)		Separation Distance			
		>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)
	Approved New	**5 m (16 ft)**	**6 m (20 ft)**	**4 m (13 ft)**	**5 m (16 ft)**
Group 2	Existing	6 m (20 ft)	7 m (24 ft)	4 m (13 ft)	5 m (16 ft)
	Approved New	**5 m (16 ft)**	**6 m (20 ft)**	**3 m (10 ft)**	**4 m (13 ft)**
Group 3	Existing	5 m (17 ft)	6 m (19 ft)	4 m (12 ft)	4 m (14 ft)
	Approved New	**4 m (13 ft)**	**5 m (16 ft)**	**3 m (10 ft)**	**4 m (13 ft)**

pressure relief device (TPRD). This modeling was intended to address concerns regarding explosive spalling conditions in the concrete tunnel structures, impact of hydrogen jet fire on bolt/epoxy assemblies that support the load of concrete ceiling panels, and the impact of the fire environment on the steel support structures via a strain analysis.

Figure 1 shows the results of the heat release rate comparison to the RijksWaterStaat (RWS) fire curve, and Figure 2 shows the same comparison to the RWS curve for the temperature in a tunnel fire. Figure 3 provides a screen capture of the steady state temperature at the ceiling resulting from the hydrogen jet fire with tunnel ventilation.

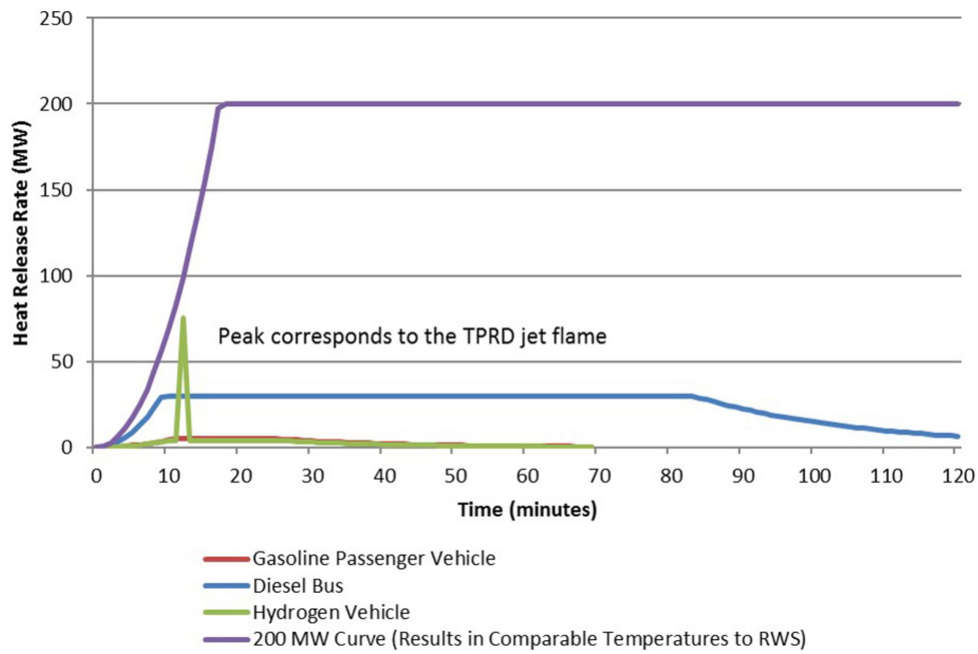

FIGURE 1. Heat release rate comparison to the RWS fire curve

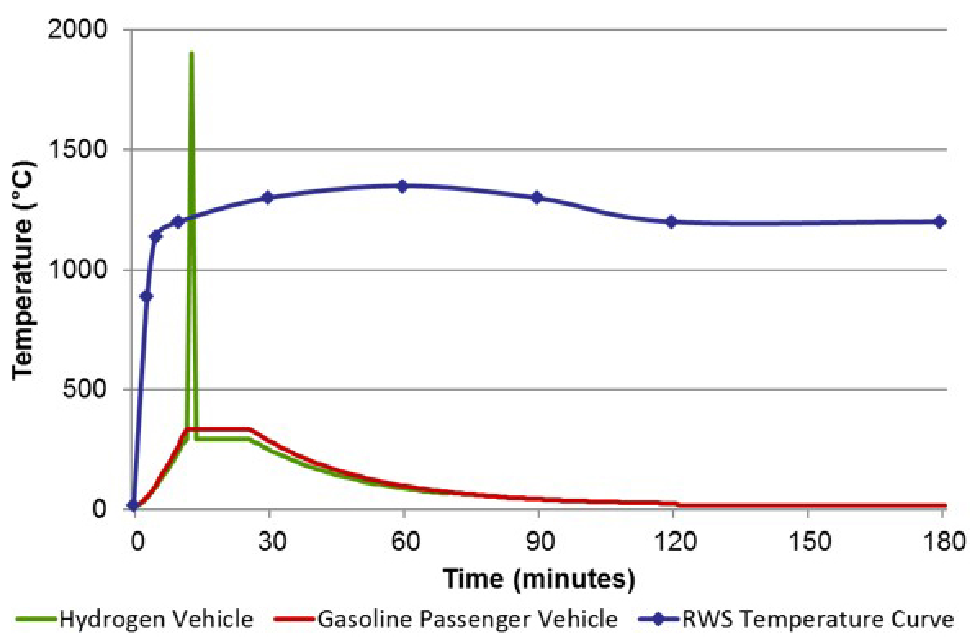

FIGURE 2. Temperature comparison to the RWS fire curve

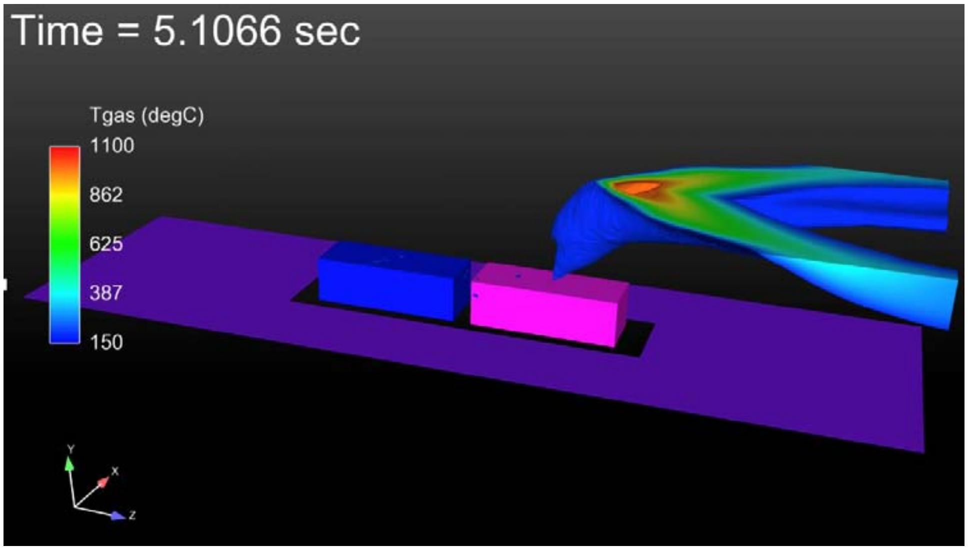

FIGURE 3. Steady-state temperature at the ceiling resulting from the hydrogen jet fire with tunnel ventilation

The results indicated that the conditions may be present for localized spalling of the concrete—but it is a very limited area (<1 m diameter) and shallow into the concrete (<1 in). The temperature in the steel hangers and the bolts/epoxy assemblies never rises above ambient temperature, so the epoxy is not compromised. The portion of the steel structure supporting the concrete panels has a temperature gradient, and the analysis of the strain impacts on the steel is nearing completion.

Demonstration of Performance-based Design for a Real-World Station

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 Models software 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 quantitative-risk-assessment-backed design processes for other alternative fuels. Efforts focused on identifying a refueling station to demonstrate alternate means of compliance in a real-world permitting situation.

CONCLUSIONS AND UPCOMING ACTIVITIES

The scientific analysis of the risks, hazards, and consequences associated with hydrogen applications is important as it informs the codes and standards governing the use of hydrogen and addresses barriers to technology advancement while addressing safety concerns. This work will continue in the future; however, the work will be assimilated under the associated program capabilities at Sandia National Laboratories, including hydrogen behavior studies, materials compatibility research, and quantitative risk analyses.

SPECIAL RECOGNITIONS & AWARDS/ PATENTS ISSUED

A 2017 Hydrogen and Fuel Cells Program R&D Award was awarded to Chris LaFleur at the 2017 Annual Merit Review and Peer Evaluation Meeting for her outstanding technical leadership in hydrogen behavior and risk assessment to enable the safe deployment of hydrogen fuel cell technologies worldwide.

FY 2017 PUBLICATIONS/PRESENTATIONS

1. C. San Marchi, E.S. Hecht, I.W. Ekoto, K.M. Groth, C. LaFleur, B.P. Someday, 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." Intern J Hydrogen Energy (proof online).

2. E.S. Hecht, P. Panda (presentation), "Validation data for cryogenic hydrogen releases and flames." Presented to Liquid

Hydrogen Separation Distance project stakeholders (web meeting), November 9, 2016. SAND2016-11548 PE.

3. C.B. LaFleur (presentation), "Hydrogen Vehicle Tunnel Safety." Presented to personnel from Massachusetts Department of Transportation, Boston Fire Department, and Massachusetts State Fire Marshal's Office, October 20, 2016. SAND2016-10789 PE.

4. C.B. LaFleur (presentation), "Hydrogen Vehicle Tunnel Safety." Presented to personnel from Maryland Department of Transportation, February 7, 2017. SAND2016-10789 PE.

5. C.B. LaFleur (presentation), "Enabling Hydrogen Infrastructure Through Science-based Codes and Standards." Presented at the 2017 Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation meeting, June 6, 2017. SAND2017-5264 PE.

REFERENCES

1. NFPA 55 *Compressed Gases and Cryogenic Fluids Code*, 2016 NFPA, Quincy, MA.

2. NFPA 2 *Hydrogen Technologies Code*, 2016 NFPA, Quincy, MA.