Sandia National Laboratories

H2FC Hydrogen and Fuel Cells Program

Enabling Hydrogen Infrastructure Through Science-based Codes and Standards

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Overview

Timeline

- Project start date: Oct. 2003
- Project end date: Sept. 2018*

*Project continuation and direction determined annually by DOE

Budget

- FY17 DOE Funding: $2.1
- Planned FY18 DOE Funding: $1.5M

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

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
L. Usage and Access Restrictions – parking structures, tunnels and other usage areas

Partners

Industry & research collaborators:
FirstElement Fuel, Inc., Linde, HySafe

SDO/CDO participation:

NFPA 2/55, DOT Tunnel Jurisdictions

International engagement:
HySafe, PRESLHY

Relevance

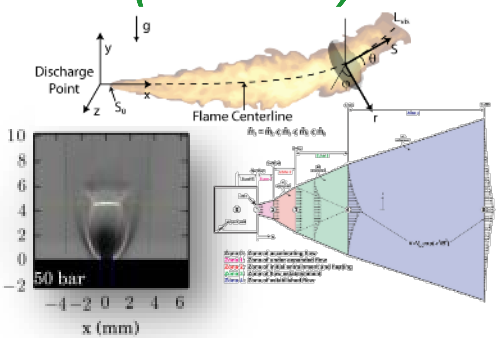
Objective: Utilize fundamental science and engineering to enable the growth of hydrogen infrastructure and improve the basis of Codes & Standards

- 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 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
L. Usage and Access Restrictions – parking structures, tunnels and other usage areas	Develop scenario specific analysis of hydrogen behavior and consequences and evaluate mitigation features

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

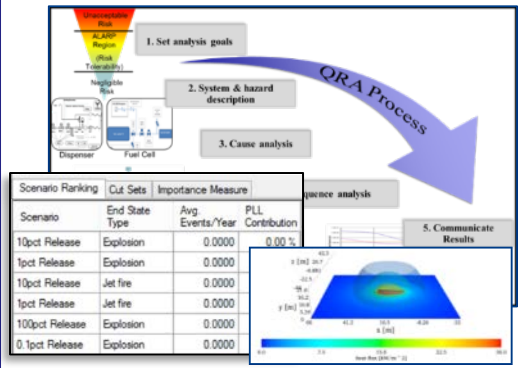
Behavior R&D (SCS 010)



Develop and validate scientific models

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

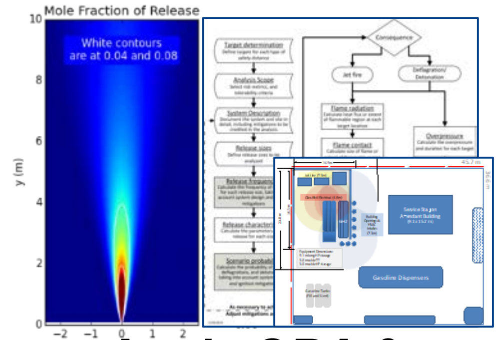
Risk R&D (SCS 011)



Develop integrated methods and algorithms

for enabling consistent, traceable and rigorous QRA

Application in SCS (SCS025)



Apply QRA & behavior models to real problems

in hydrogen infrastructure and emerging technology

Developing methods, data, tools for H_2 safety & SCS

Approach / FY17-18 Milestones

Impact Areas	**Completion date or status**
Science-based Hydrogen Storage Code Improvements	
• **Update Science Basis of Liquid Separation Distances in NFPA 2/55**	
• Analyze scenarios for basis of code revision using near field model • Characterize scenarios with large scale release experiment results and models • Develop risk-informed separation distance revision proposals to code	Ongoing December 2019 2020
• **Update Gaseous Separation Distances Based on Revised Risk Criteria**	
• Distances approved by technical committee • Address public comments, recalculate for second draft of NFPA 2	January 2017 September 2018
• **Synchronize with International Standards**	
• Kick off and strategy development for EU PRESLHY project	April 2018
• **Evaluation of Existing Tunnel for FCEV Safety**	
• Comprehension of Massachusetts specific safety concerns • Initial calculations of FCEV compared to traditional vehicle fire HRR • Develop detail heat transfer and CFD models of tunnel fire • Publish report and deliver to MassDOT	October 2016 January 2017 July 2017 October 2017
• **Demonstrate Performance-based Design for a Real-World Station**	
• Station selection • Develop PBD design, justification and station permitting	In Progress Pending Station Selection

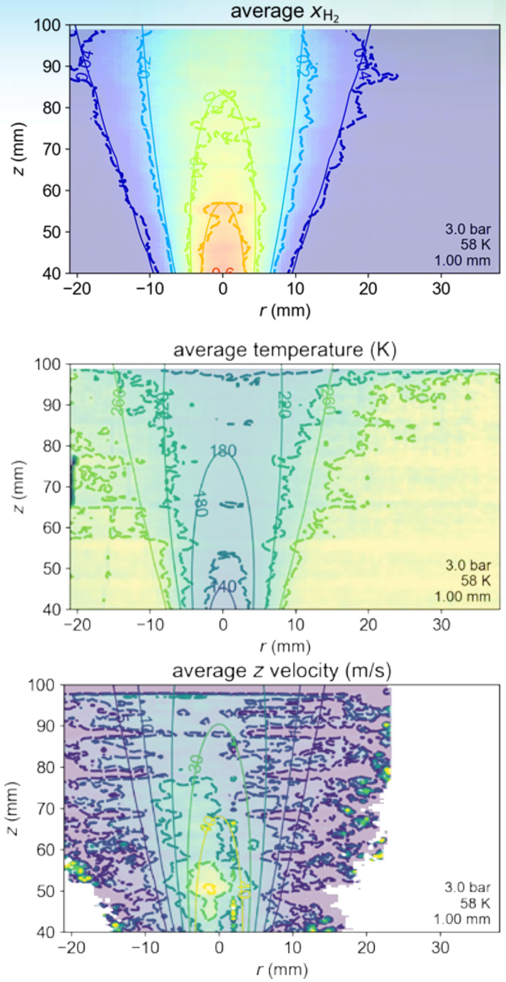
Progress: Real World Application of Alternate Means

- Goal: Establish alternate means as a viable station permitting option with an industry partner
- Progress:
  - Established a new CRADA with industry partner (FirstElement Fuel, Inc.)
  - Nineteen planned LH2-based refueling stations
  - Target one issue that affects multiple stations
  - Develop calculations to support Alternate Means justification
- Permit for an Alternate Means station that challenges separation distances will be developed

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: LH2 Informing Science-based Code Revisions

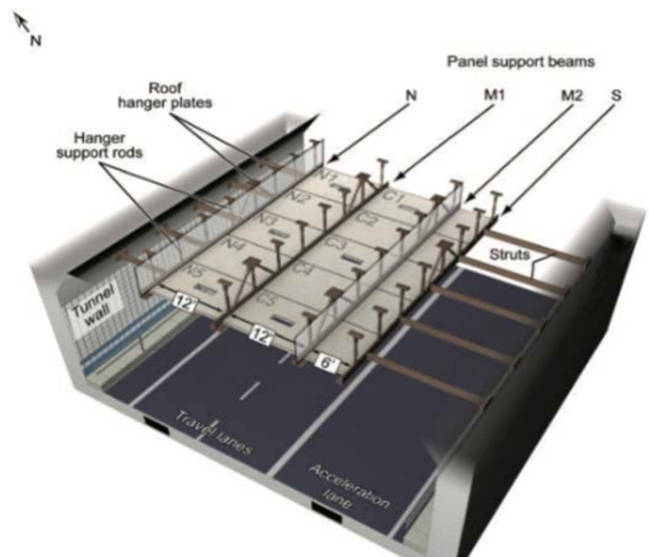
- Goal: Use QRA tools and methods to revise bulk liquid hydrogen system separation distances in NFPA 55/NFPA 2
- Progress:
  - Consensus –based code committee selects scenarios of concern to model to evaluate code requirements
  - Validation of near-field model complete including mole fraction, temperature and velocity
  - Development of diagnostic to measure full-scale cold vapor releases underway
  - Development of full-scale release experiments underway
  - Details given in SCS-010 AMR presentation



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

Approach: Risk and Modeling of FCEV in Tunnels

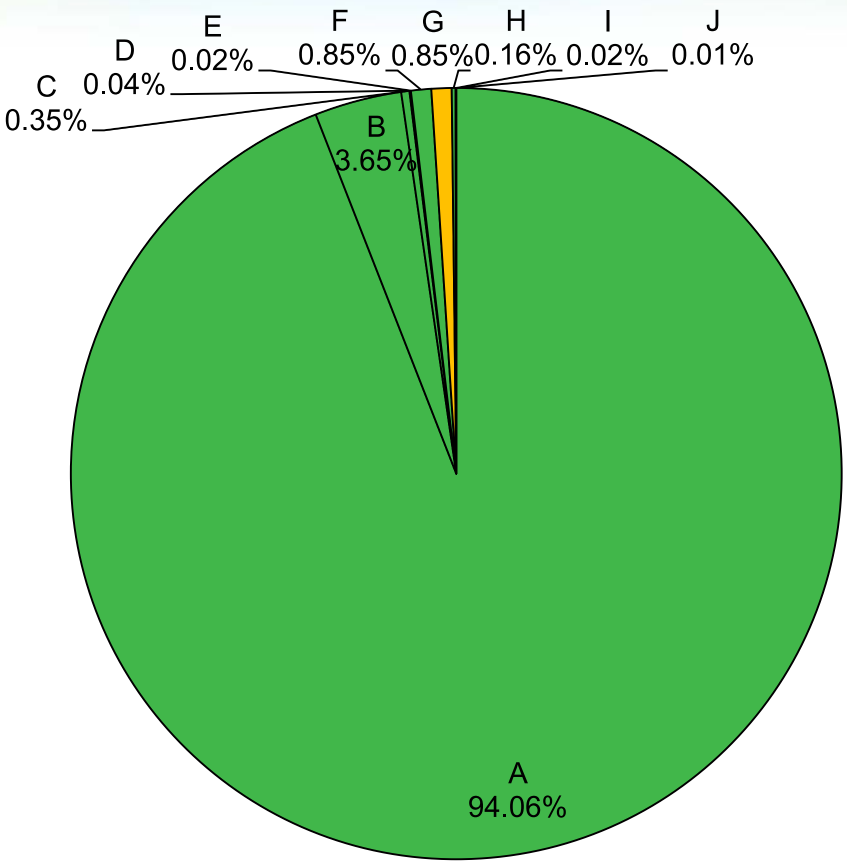
- Objective: Provide the necessary information to authorities in the Northeast Corridor to determine if FCEVs will be permitted in tunnels
- Comprehensive Risk Analysis
  - What could happen, what are the consequences if it does happen, what are the chances of it happening
  - Attempt to quantify the probabilities of each scenario
- Evaluation of the Consequences, if uncertain
  - Modeling and analysis of a Thermally Activated Pressure Relief Device (TPRD) release
- Listen to concerns of Authorities Having Jurisdiction (AHJ)
  - Investigate and address each concern



Board, National Transportation Safety,(2007)

Accomplishments: Risk Analysis of FCEV in Tunnels

- **GREEN** Scenarios A, B, C, F, and H, where there is no additional consequence resulting from the FCEV, clearly dominate the probability of scenarios
- **YELLOW** Scenario G postulates an FCEV crash were the TPRD activates due to temperatures from an external fire
- **RED** Scenarios E and J involve delayed ignition but are very low probability

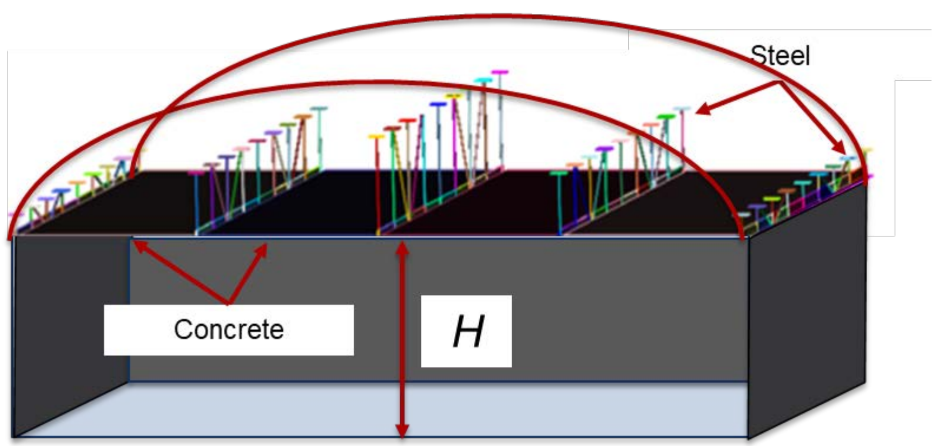


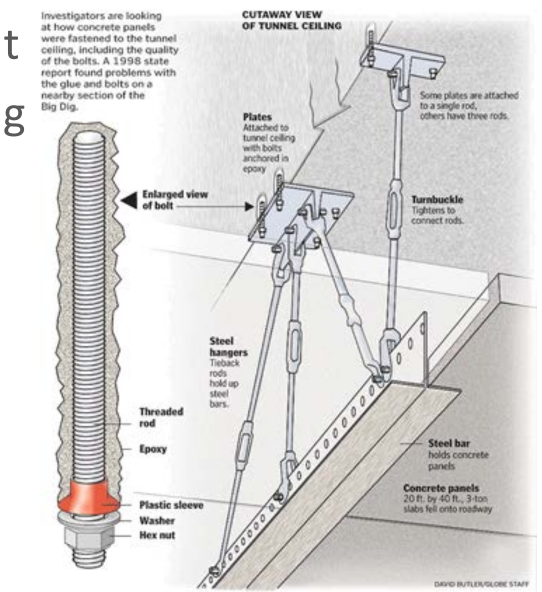
Probability of each branch line scenario, given an accident in a tunnel

Scenario G with the potential for increased consequence due to hydrogen will be analyzed further and modeled.

Accomplishments: Modeling Multiple Tunnels

- TPRD release scenario (G)
  - Gasoline from other vehicle ignites, external fire engulfs FCEV, activates the TPRD
  - H_2 immediately ignited and a jet fire results aimed toward tunnel ceiling
  - A 125-liter, 70 MPA tank with a TPRD orifice of 2.25 mm is analyzed with a blowdown of approximately 300 sec
- Analyzed CANA, Sumner & Ted Williams Tunnels to quantify:
  - Distortion of steel frames supporting concrete panels
  - Impact on capacity of epoxy anchors under anticipated heat
  - Potential for spalling of concrete tunnel roof slab and ceiling panels

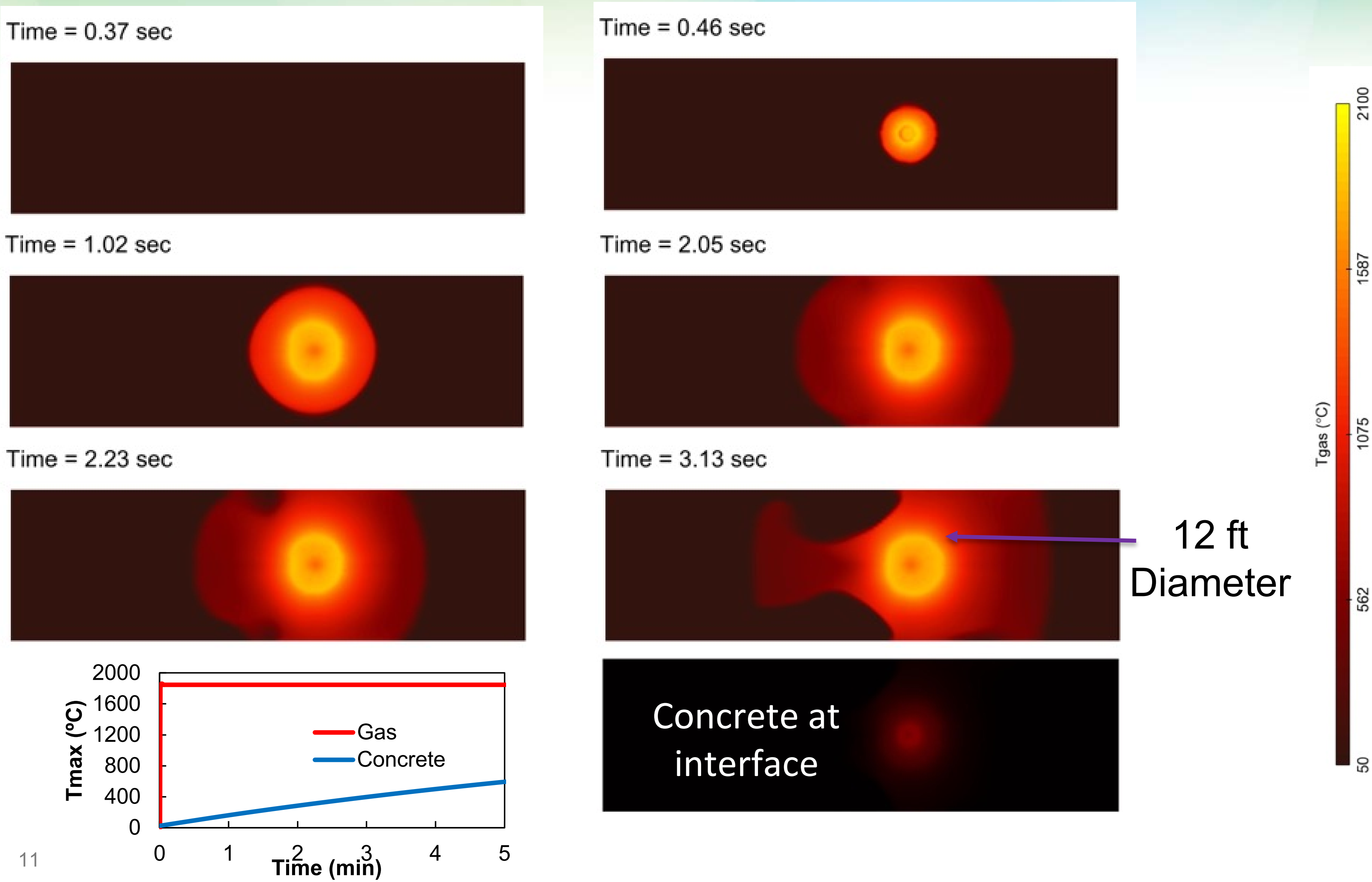




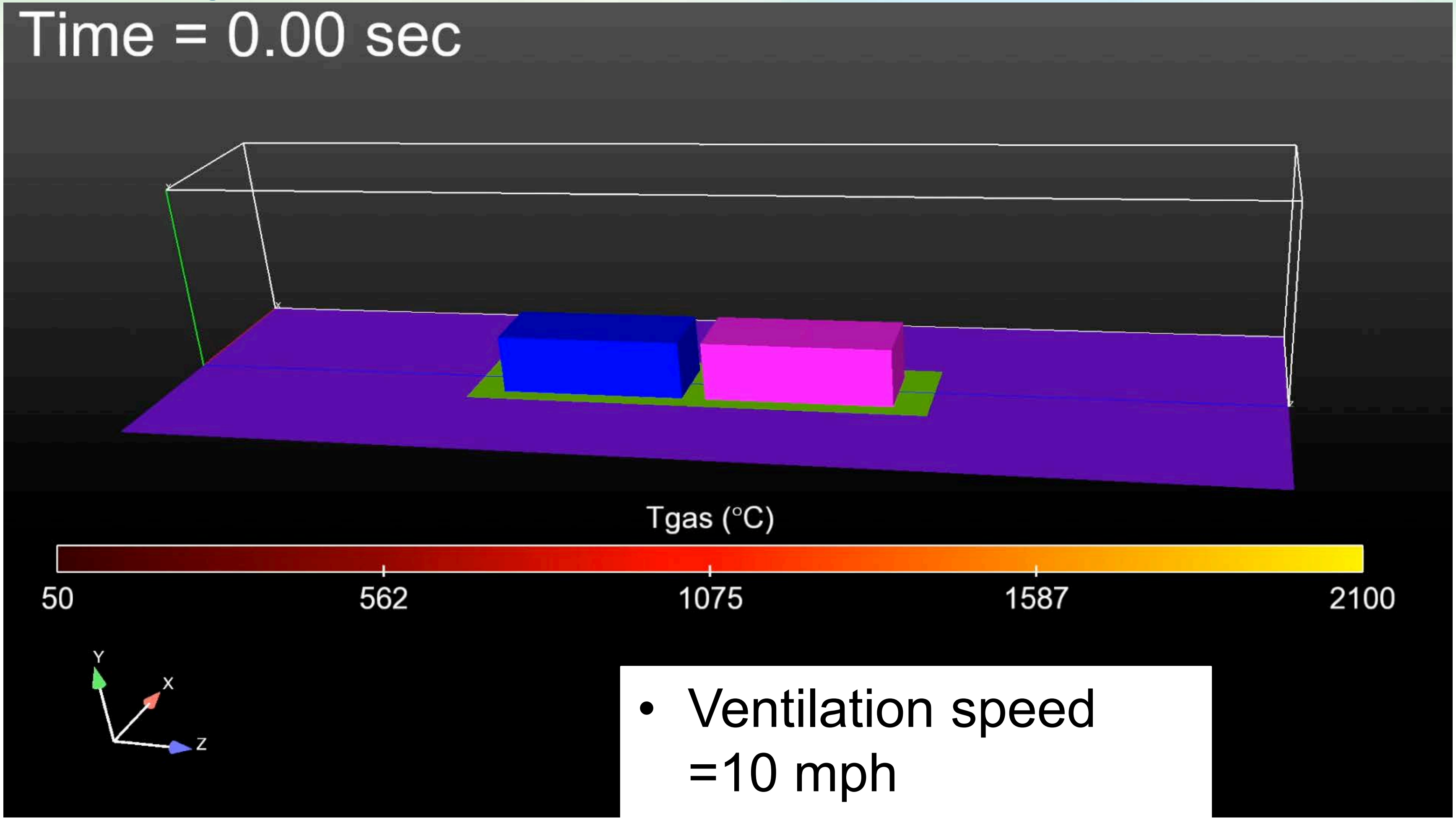
Board, National Transportation Safety,(2007) Sandia National Laboratories

H2FC Hydrogen and Fuel Cells Program

Accomplishments: CANA Tunnel CFD, No Ventilation



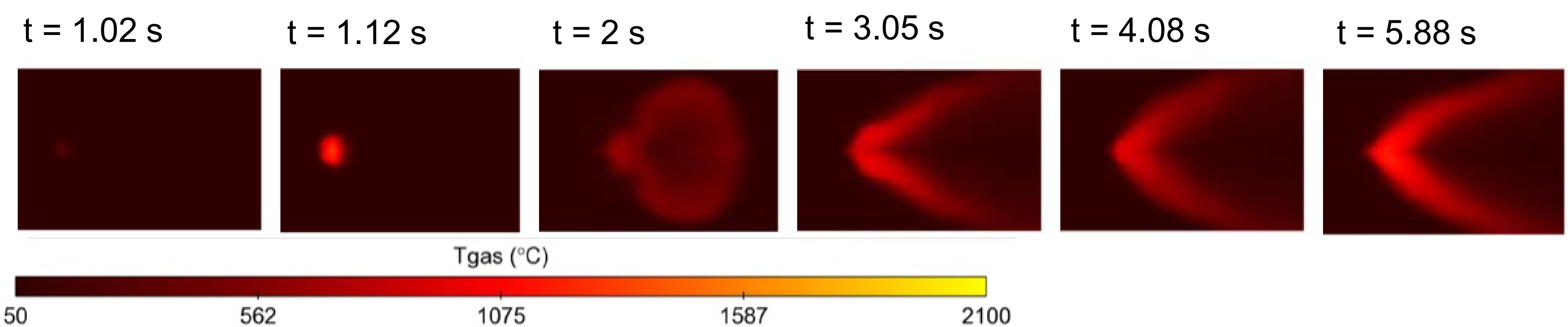
Accomplishments: CANA Tunnel H_2 Jet Flame CFD Model – Gas Temperature With Ventilation

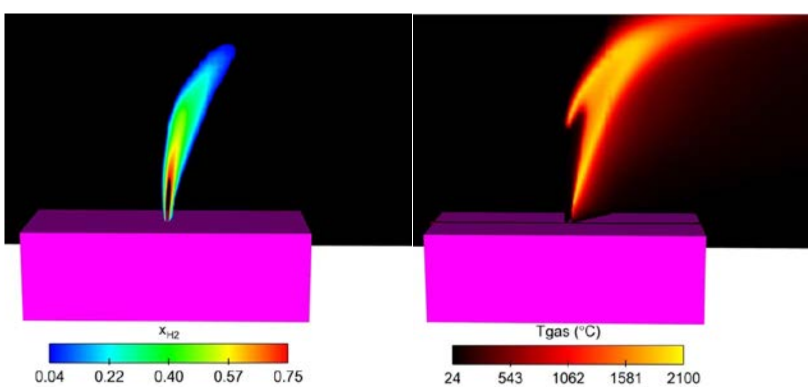


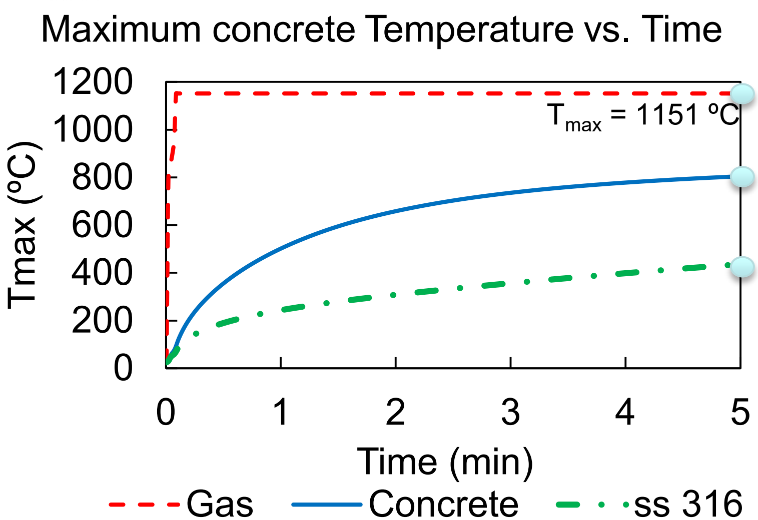
- Ventilation speed =10 mph

Accomplishments: CANA Tunnel CFD with Ventilation

- Flame does not reach ceiling, but hot gas mixture does.
- The separation of the jet at the ceiling interface is caused by a counter-rotating vortex pair generated by the jet in crossflow







Accomplishments: Tunnel Results

- Potential for **explosive spalling**:
  - Modeling showed that conditions are present that may result in localized spalling in the area where the hydrogen jet flame impinges the ceiling
  - Steel deflection is minimal
  - Note that the hydrogen heat release rate was over-predicted, so the temperature observed should be lower
- Effect of heat on the **epoxy**:
  - Maximum temperature at epoxy/bolt location is ambient, well below failure point of 90 ^{o}C, even under the worst case, conservative condition
- Effect of heat on the **steel support structure**:
  - Maximum temperature of steel hangers exposed directly to the hydrogen jet flame is 706 ^{o}C after 5 minutes of impingement for the case with no ventilation
- Analysis focused on short duration H_2 jet flame. Hydrocarbon fuel/vehicle fire would be a longer duration and resulting heat was not analyzed and may result in spalling concrete
  - Only the hydrogen fire was analyzed because it posed a new hazard

Response to Previous Year Reviewers' Comments

2017 AMR Reviewer Comment	Response
"Lack of progress on the real world station is a weakness" "One area that appears to be moving more slowly is the performance-based design for a real-world station. There are many factors that could be contributing to this that are understandable."	A new CRADA partner with 19 planned stations has been identified and work has begun to implement alternate means permit on a real world station.
"The project should conduct field data analysis and validation testing to support science-based computation."	This work is covered in SCS-010 for the LH2 behavior work. Funding for large-scale tunnel validation is not available at this time.
"Project weaknesses include (1) lack of control of the inputs needed to complete the work, resulting in large delays, (2) inability to come up with alternative approaches to speed progress, and (3) looking at separation distances as the objective rather than looking at alternative methods that could be more effective and used more broadly (e.g., in situations in which even reduced distances might be impossible)."	Alternative approaches are actively being worked and a new industry partner is working on identifying specific issues and real world stations for implementation. Unfortunately, separation distances are already instituted in the existing codes. The consensus-based codes rely on agreement of the majority of committee members to agree on changes. This is a barrier to modification of the basis of the code requirements.

Collaborations

Relationship	Partner	FY17 - FY18 Role
CRADA	**Industry:** FirstElement Fuels, Inc.	CRADA for In-kind support, data exchange for QRA tool and QRA demonstration activities, real world station for alternate means permitting
CRADA	**Industry**: Frontier Energy (Manager of the California Fuel Cell Partnership)	Develop industry stakeholders in support of LH2 Behavior Characterization
CRADA	**Code Industry**: Fire Protection Research Foundation (NFPA)	Lead stakeholder oversight panel and enable link to NFPA code process
Collaborator	**International :** IA 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

- Science-based Code Improvements
  - Characterization of the extent of hydrogen concentrations and heat fluxes (if ignited) result in more restrictive code requirements.
  - Liquefied hydrogen system leak size and frequency data is not available to allow the QRA to inform the code committee
  - Consensus agreement on suitable means of quantifying hydrogen system mitigation features is not reached
- Hydrogen Tunnel Safety
  - Local AHJ permissions may not be granted, despite scientific analysis.
  - Different jurisdictions grant differing permissions for FCEV, resulting in complicated use allowances.

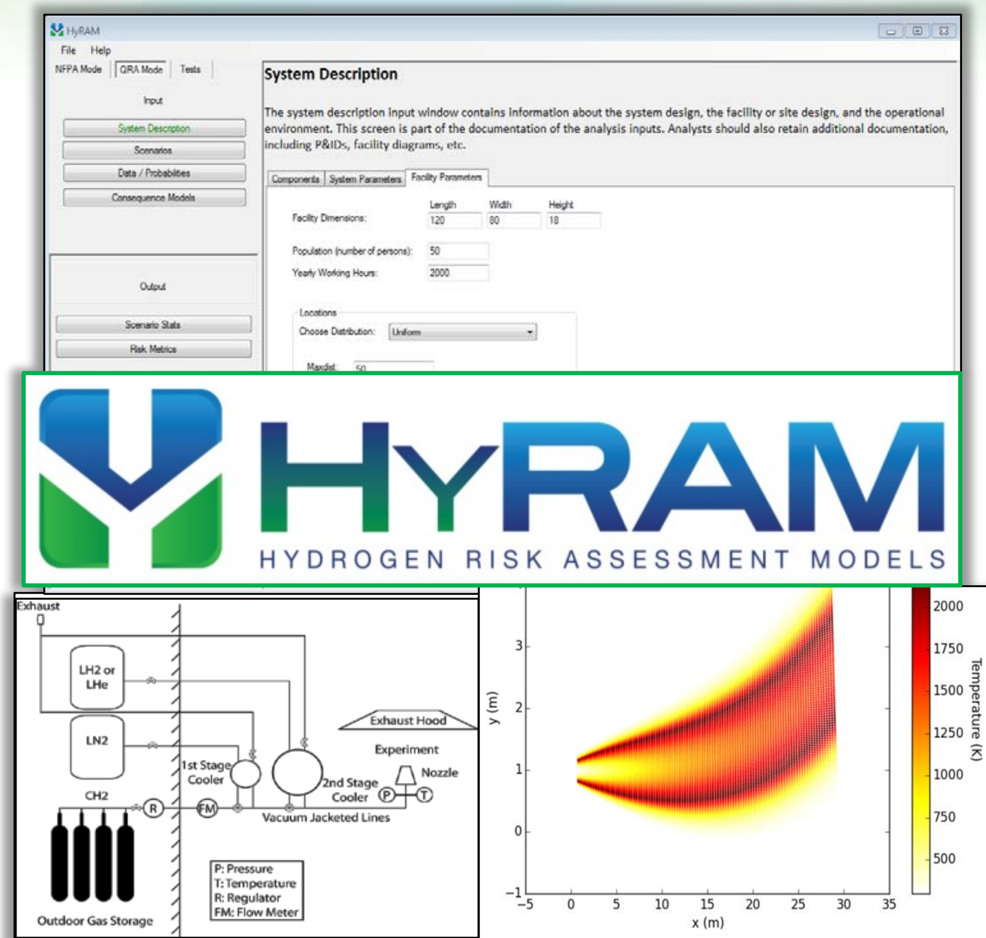
Proposed Future Work

- Remainder of FY18
  - Support NE Tunnel Jurisdictions with analysis and characterizations for decision support
  - Provide LH2 system scenario analysis to code committees as determined by consensus needs
  - Provide alternate means analysis to support real-world station
- FY19
  - Refine characterization of LH2 releases with validated cold plume release and identify full scale modeling needs to provide sound scientific basis for revised bulk LH2 separation distances in NFPA 2/55.
  - Support alternate means permit for LH2 refueling station
- Out-years
  - Characterize full bulk LH2 release scenarios to support mid-cycle temporary interim agreement (TIA) code revision

- Any proposed future work is subject to change based on funding levels.

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



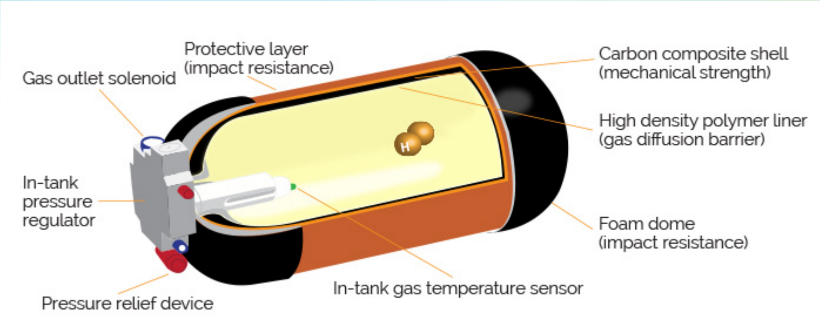
Summary

- **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
- **Northeast Corridor Tunnel Safety Analysis:**
  - Addresses: Usage and access restrictions – parking structures, tunnels and other usage areas
  - By: Providing scientific analysis for regulatory decision support for FCEV access
- **Alternate Means of Code Compliance**
  - Addresses: Education of AHJs, insufficient technical data to revise standards
  - By: Validating and demonstrating alternative methods of code compliance

Technical Back-Up Slides

Velocity of H_2 Tank Blowdown

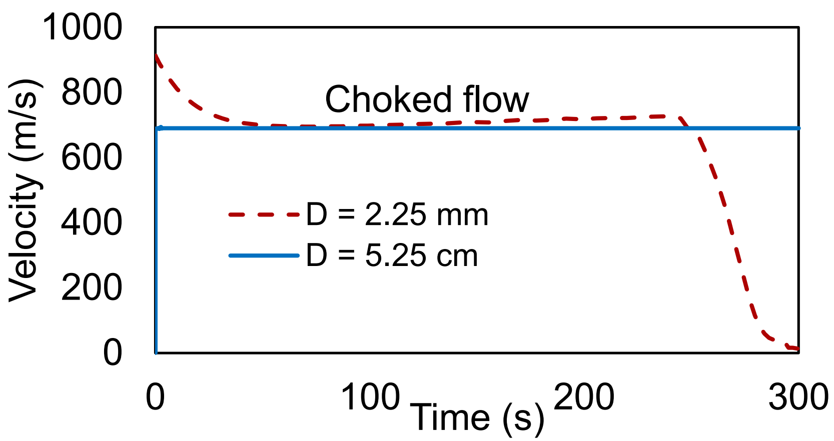
- Valve orifice diameter was adjusted due to mesh constraint
  - Actual valve diameter 2.25 mm → CFD orifice diameter 5.25 cm
  - Same mass flow rate by adjusting velocity under-predicts flame impingement duration on the ceiling

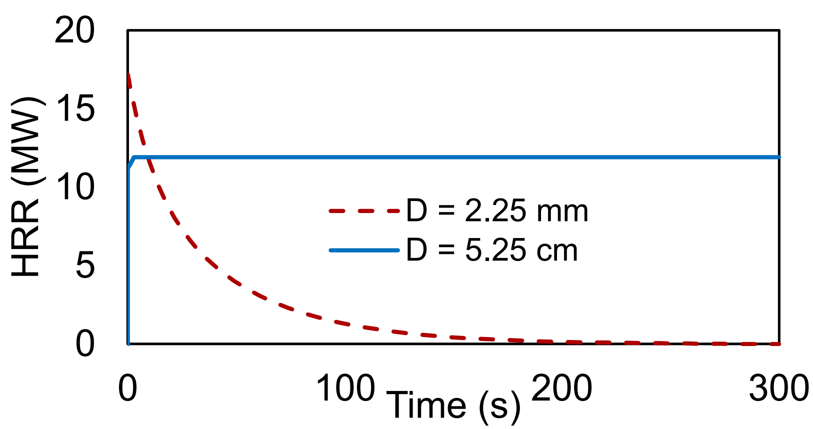


https://cafcp.org/emergency-responders

- Modeled: 700 m/s over 5 minutes
  - Will over-predict amount of mass released, but captures momentum and flame length
  - Heat release rate is also over-predicted,

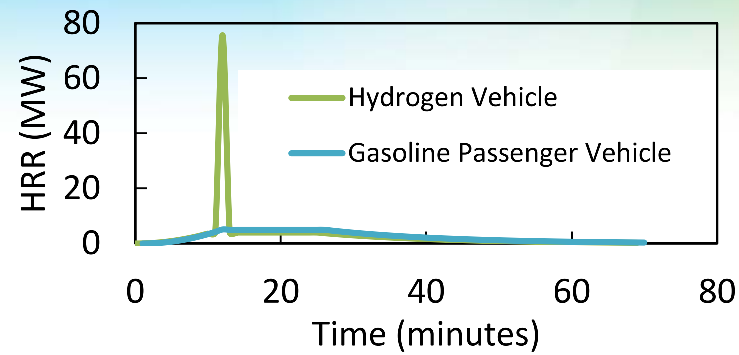
$$HRR = \dot{m}_0 \Delta H_c$$

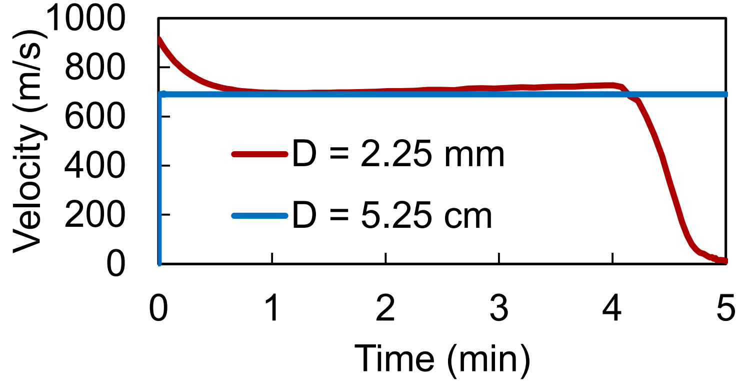


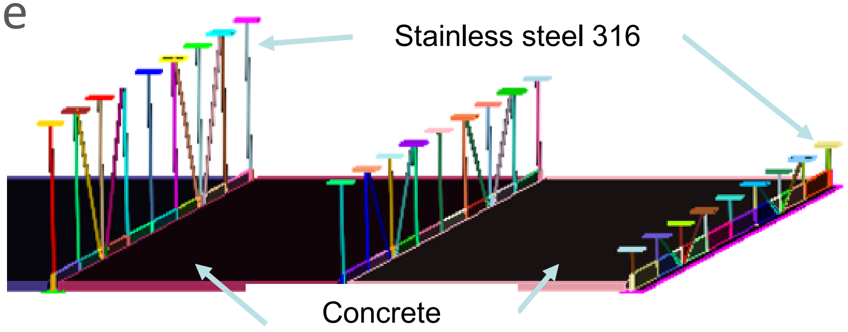


Important Conservative Assumptions

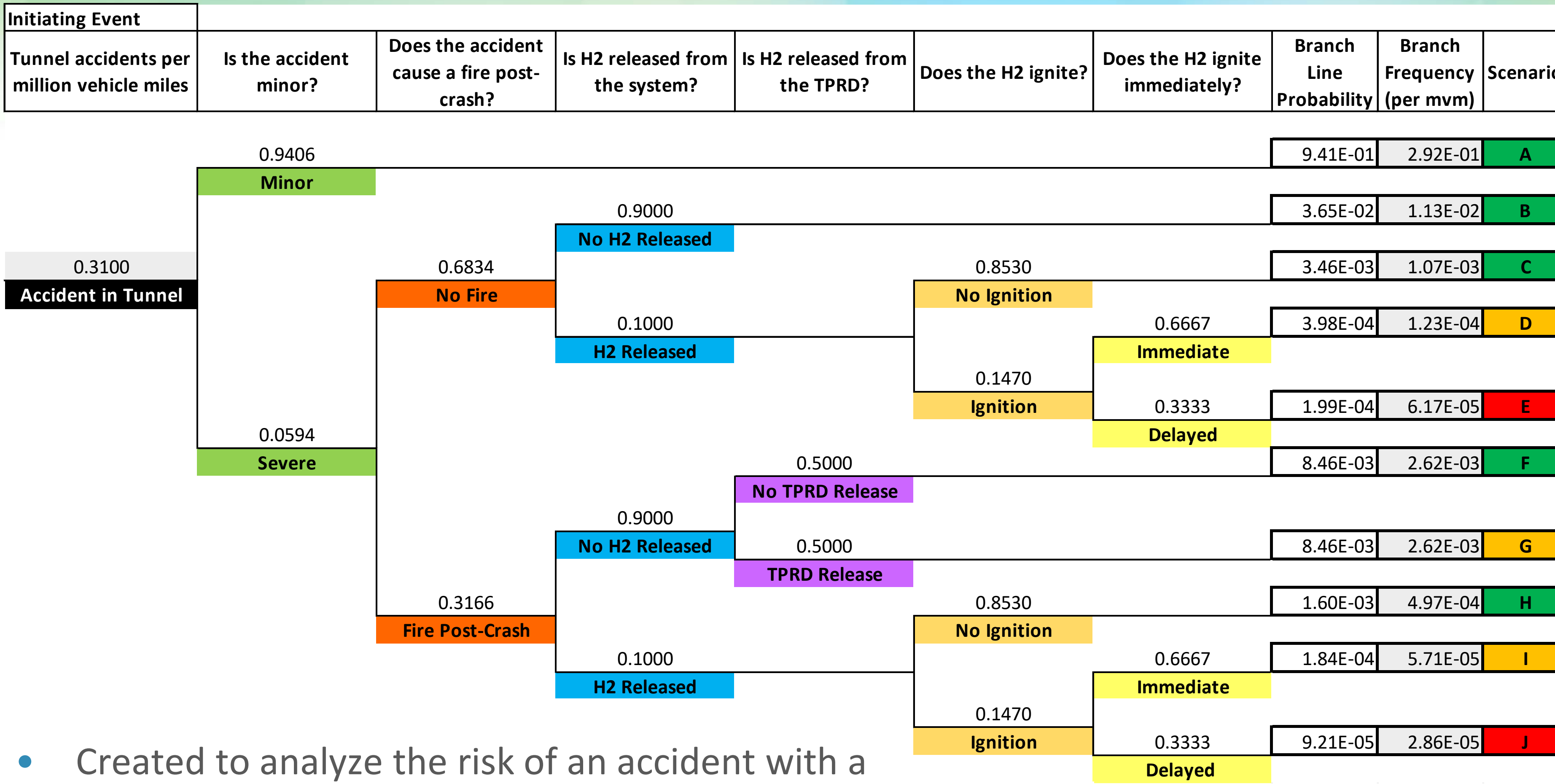
- Only one fuel can be burned at a time in the simulations
  - Simulations include only hydrogen jet flame
  - Heat Release Rate (HRR) from hydrogen is constant for the 5 minutes of the H_2 release
- Constant choked velocity was used for the release of hydrogen (no blowdown over time)
  - Blowdown would last 5 minutes
  - Ensured worst case flame heat release rate and duration of impingement
- The flame was located directly under the shortest steel support to represent the worst case







Accomplishments: Risk Analysis of FCEV in Tunnels



- Created to analyze the risk of an accident with a hydrogen fuel cell vehicle
- The event tree illustrates the chronological sequence of events involving the successes and/or failures of the system components

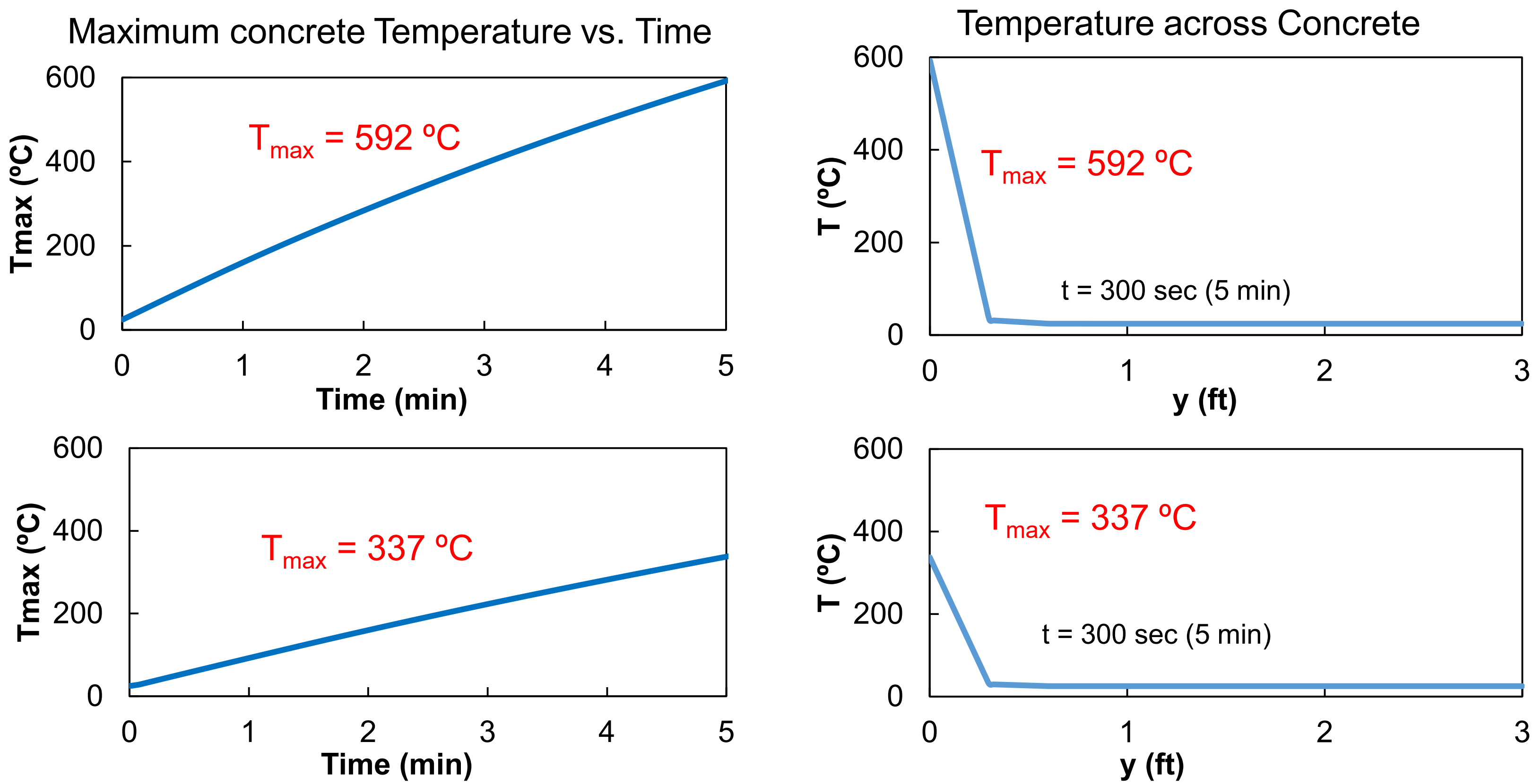
Risk analysis used to identify possible scenarios and focus CFD modeling efforts on scenarios with highest risk

Accomplishments: Heat Transfer Model Predicts Temperatures Throughout Concrete Panels

CANA Tunnel

No Ventilation

With Ventilation



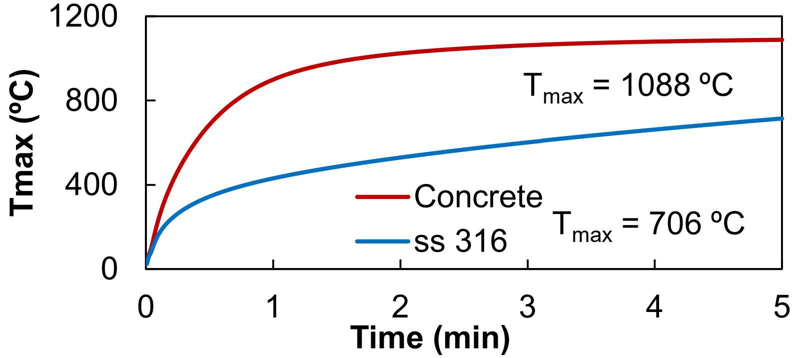
It is much less likely to have explosive spalling when tunnel ventilation is operating

Accomplishments: Effects on Structural Elements Predicted

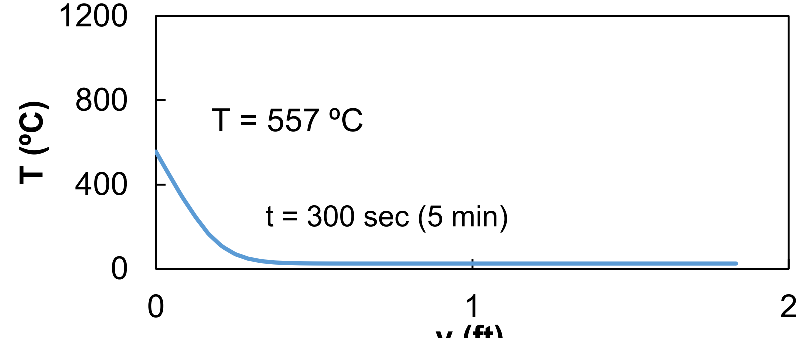
TW Tunnel

No Ventilation

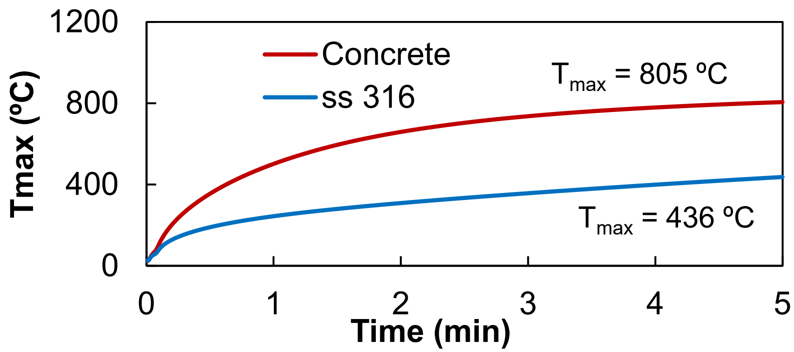
Maximum concrete Temperature vs. Time



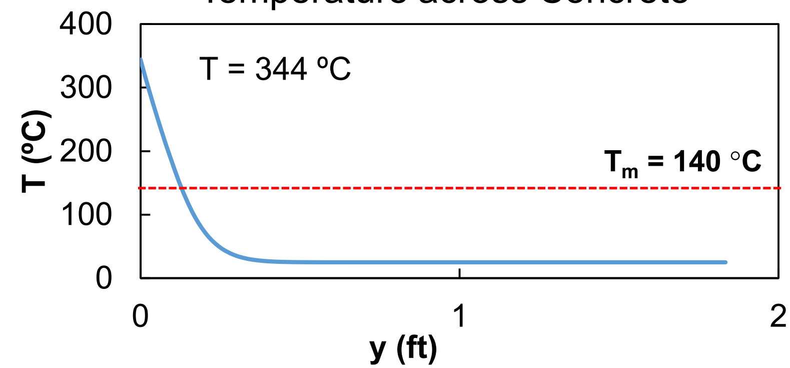
Temperature across 316 SS hanger



With Ventilation



Temperature across Concrete



The epoxy will not reach the failure temperature of 90 °C