SAND2018-10662PE

Quantitative Risk Analysis of Hydrogen Transport Through Tunnels

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Sandia National Laboratories

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Risk and Modeling of FCEV in Tunnels

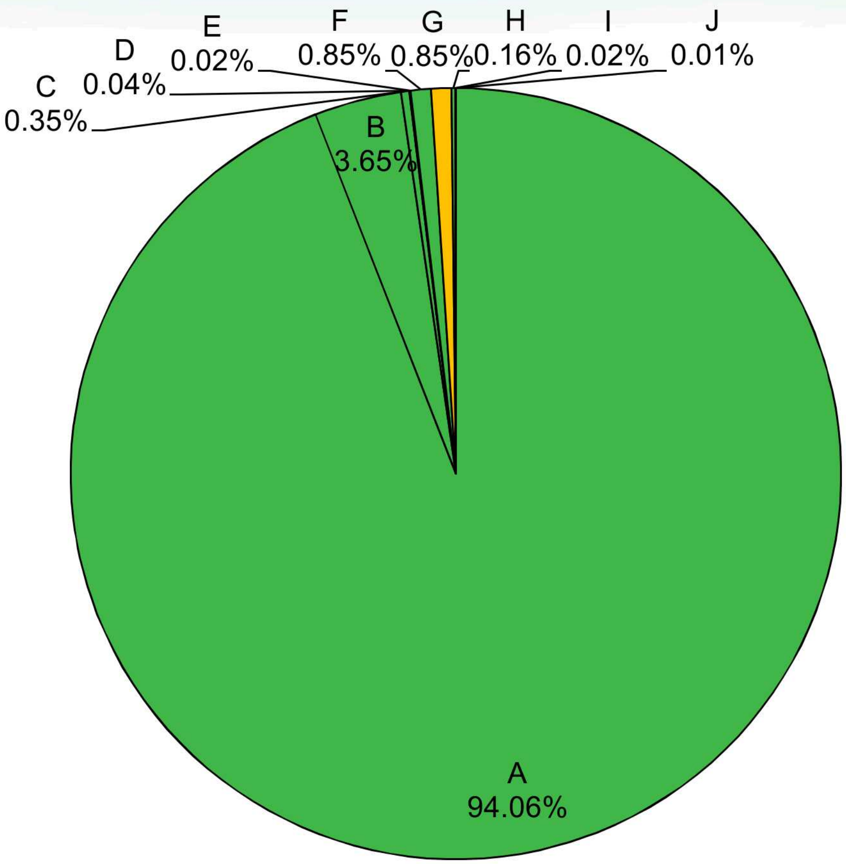
- Objective: Provide the necessary information to authorities in the Northeast Corridor to determine if FCEVs should be permitted in tunnels
- Comprehensive Risk Analysis
  - What could happen, what are the consequences if it does happen, what are the chances of it happening
  - Attempt to quantify the 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)

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

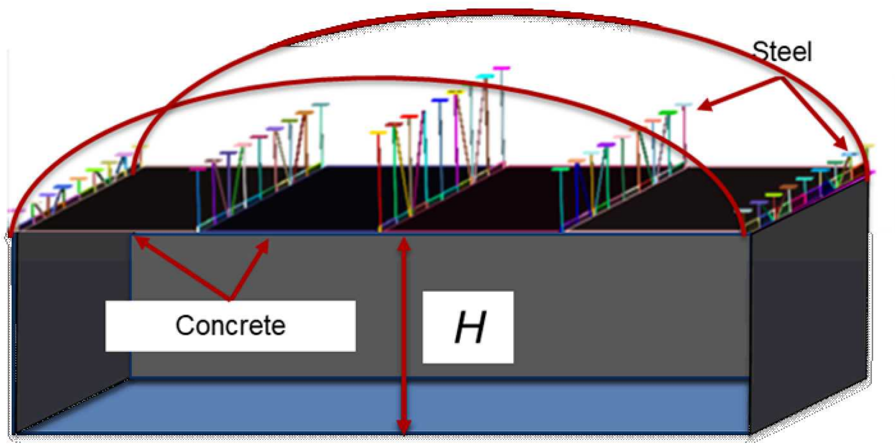
Scenario G with the potential for increased consequence due to hydrogen will be analyzed further and modeled.

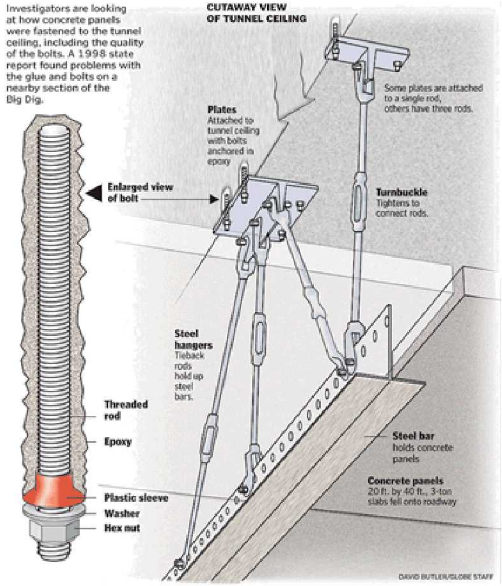


Probability of each branch line scenario, given an accident in a tunnel

Modeling Multiple Tunnels

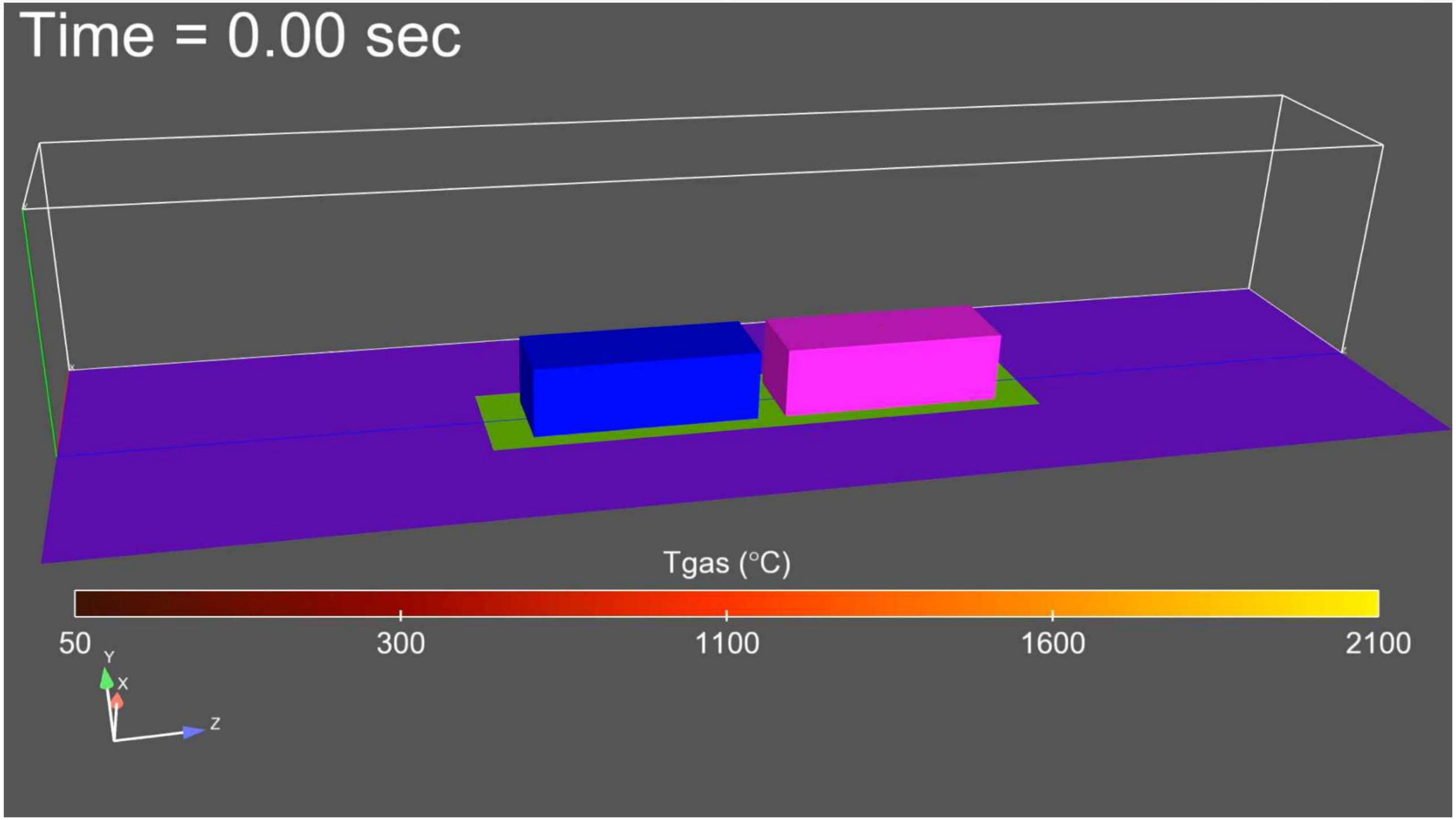
- TPRD release scenario (G)
  - Gasoline from other vehicle ignites, external fire engulfs FCEV, activates the TPRD
  - H_2 immediately ignited and a jet fire results aimed toward tunnel ceiling
  - A 125-liter, 70 MPA tank with a TPRD orifice of 2.25 mm is analyzed with a blowdown of approximately 300 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



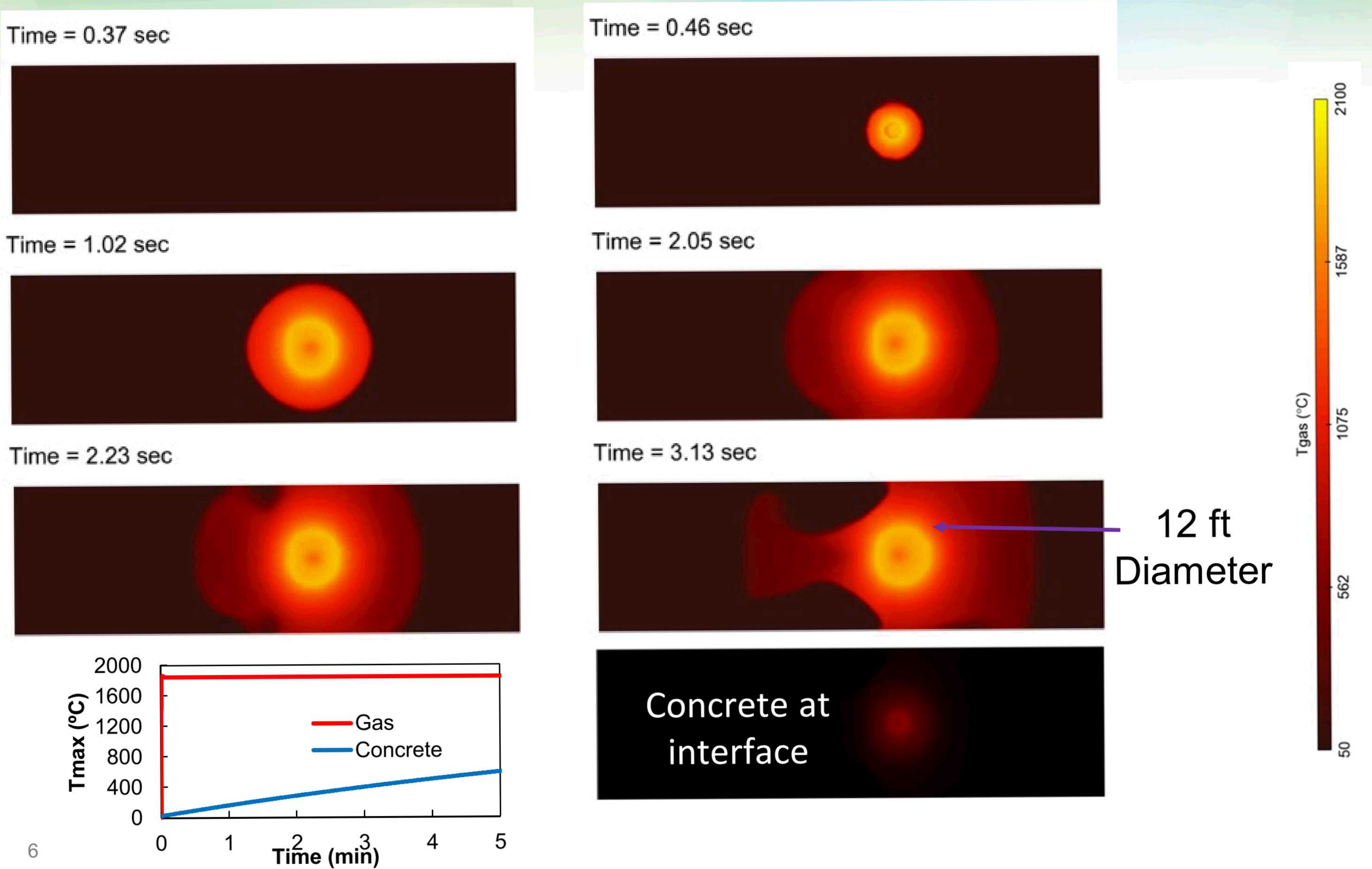


Board, National Transportation Safety,(2007)

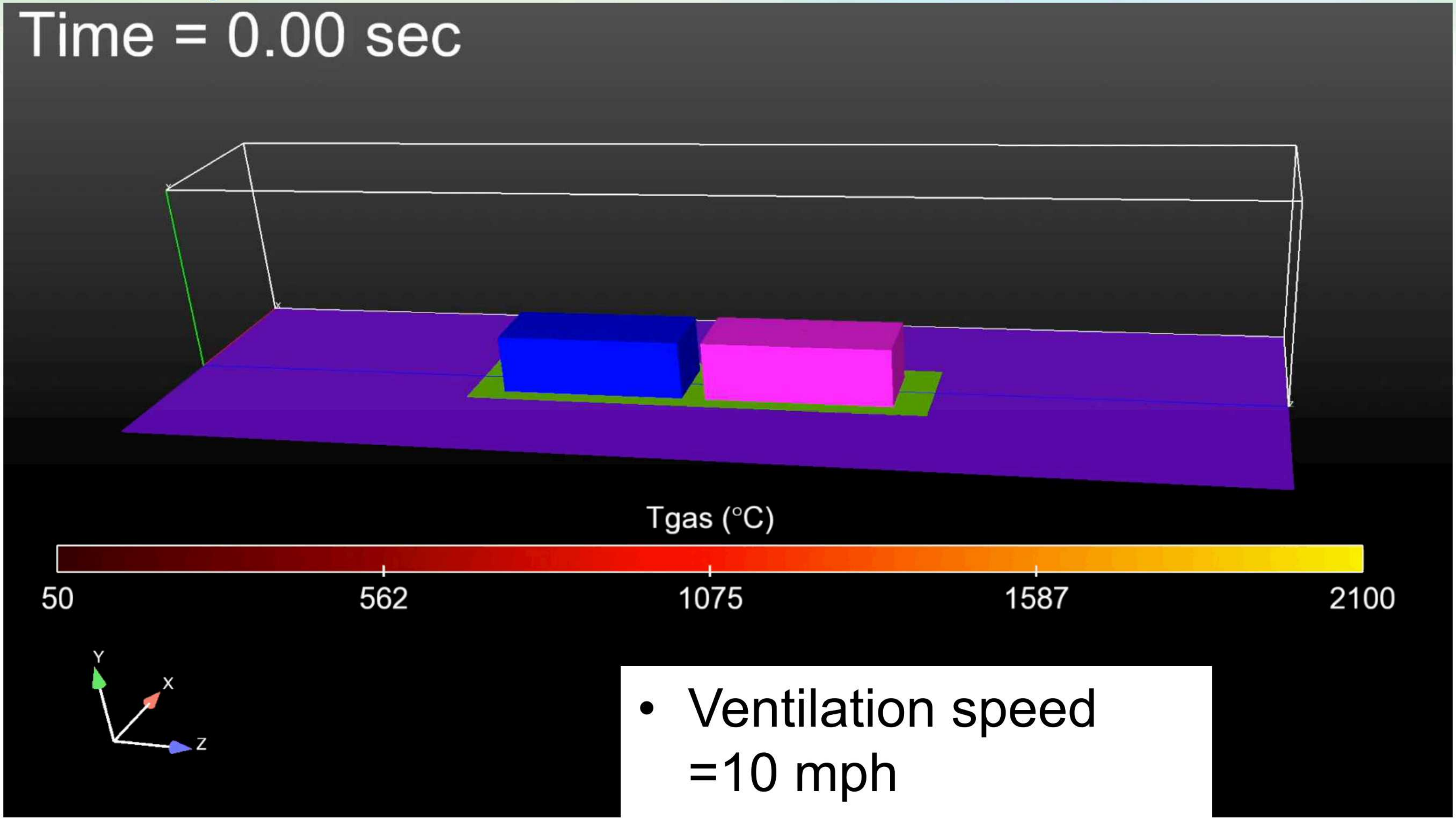
CANA Tunnel H_2 Jet Flame CFD Model – Gas Temperature Without Ventilation



CANA Tunnel CFD, No Ventilation



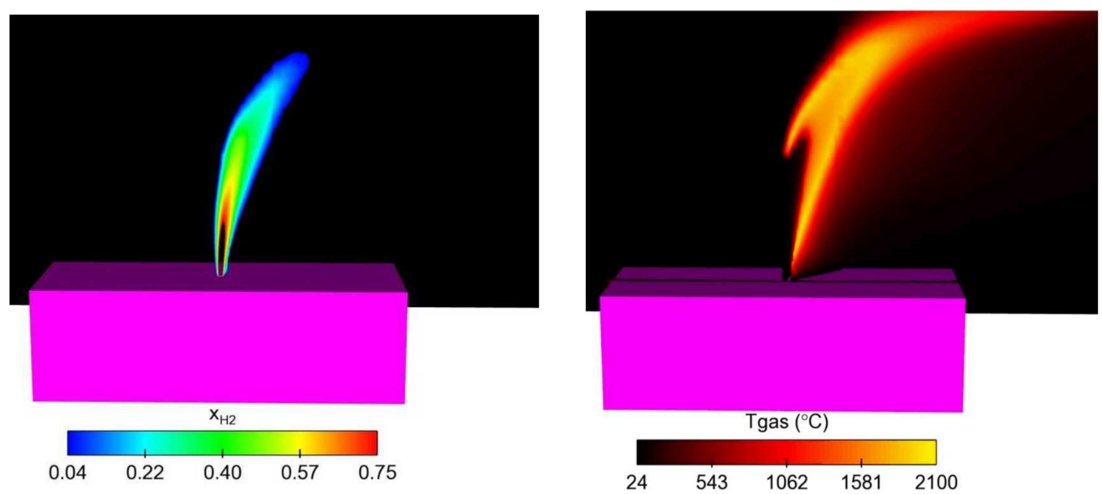
CANA Tunnel H_2 Jet Flame CFD Model – Gas Temperature With Ventilation



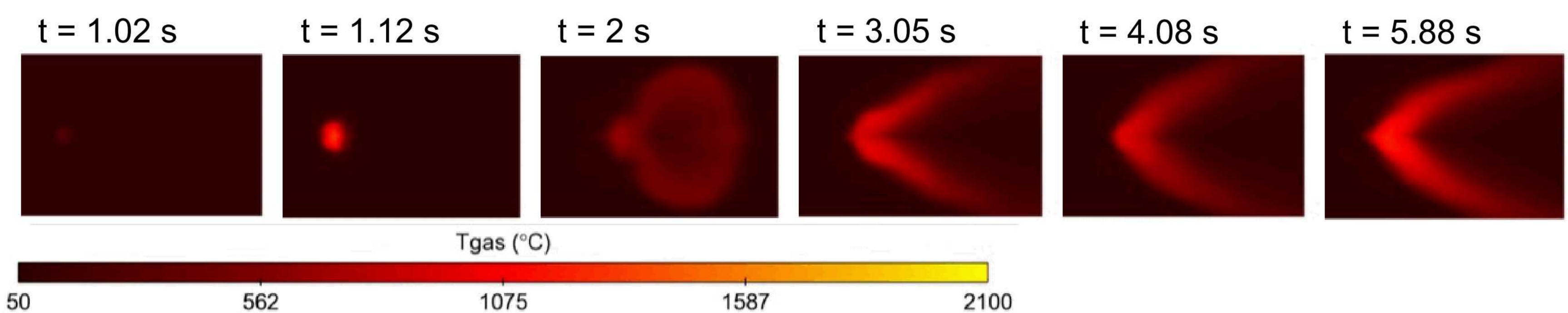
- Ventilation speed =10 mph

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



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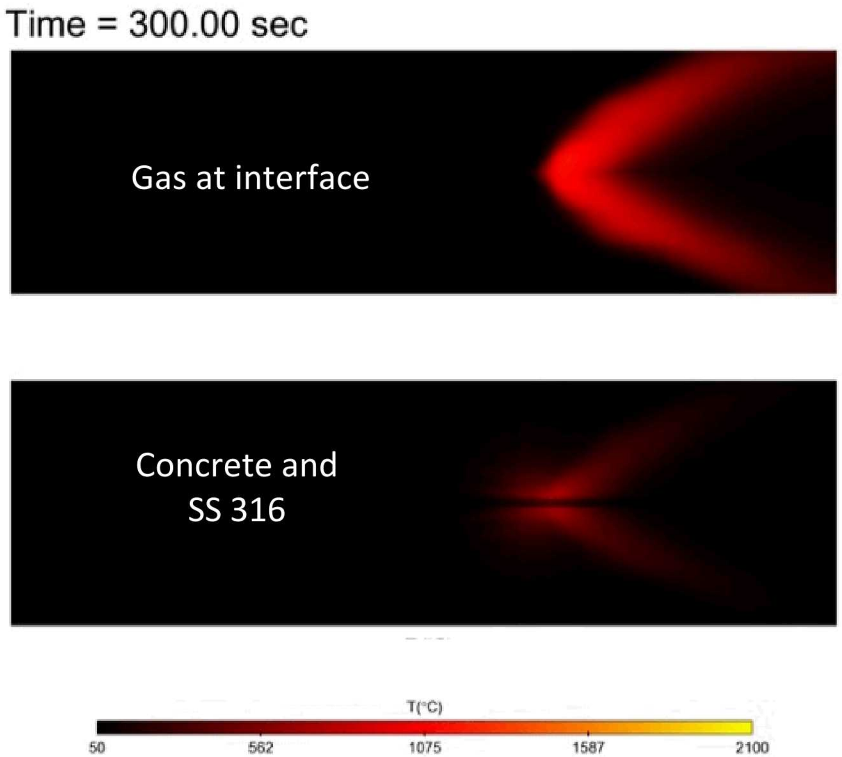
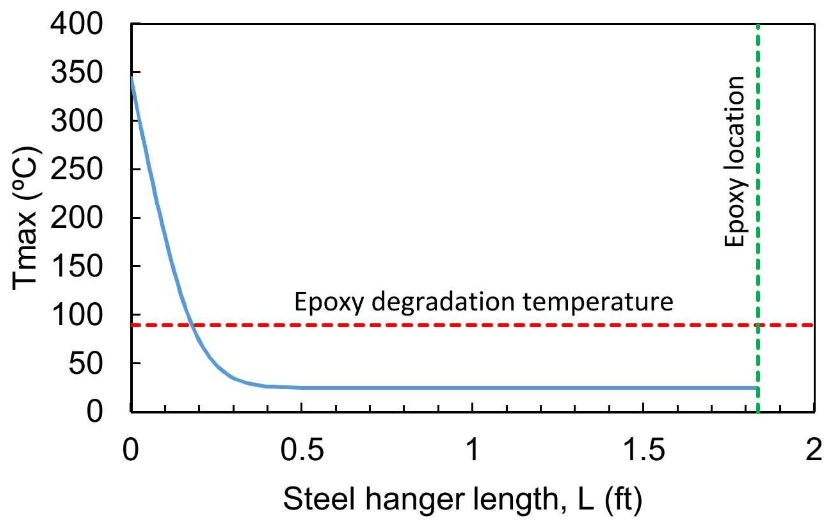




Tunnel Results

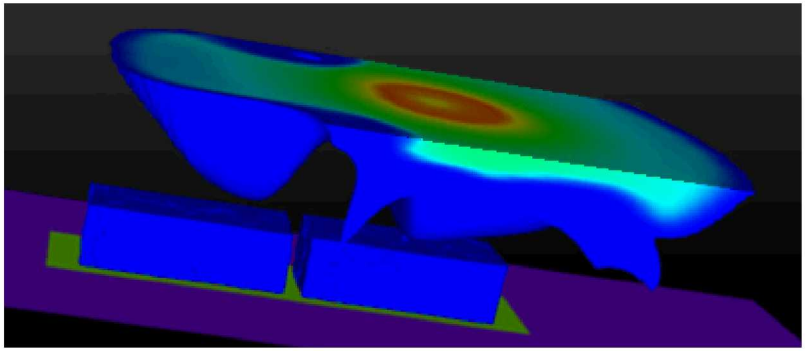
- Potential for **explosive spalling**:
  - Modeling showed that conditions are present that may result in localized spalling in the area where the hydrogen jet flame impinges the ceiling
  - Steel deflection is minimal
  - Note that the hydrogen heat release rate was over-predicted, so the temperature observed should be lower
- Effect of heat on the **epoxy**:
  - Maximum temperature at epoxy/bolt location is ambient, well below failure point of 90 °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 °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

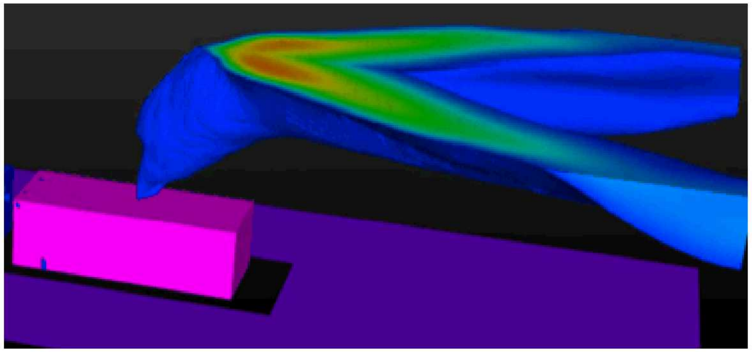
Remaining Challenges and Barriers

- 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

- Support NE Tunnel Jurisdictions with analysis and characterizations for decision support





Thank you!

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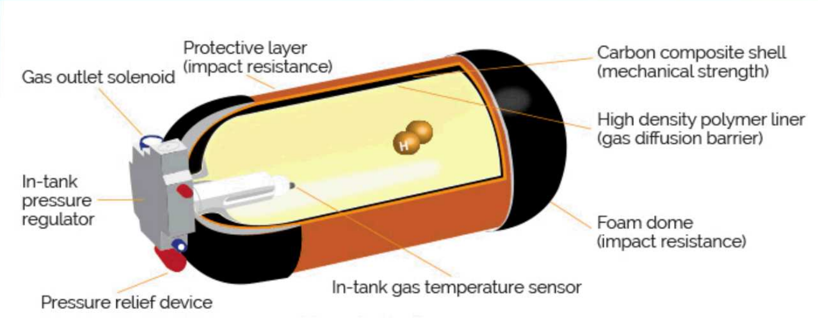
Technical Back-Up Slides

Velocity of H_2 Tank Blowdown

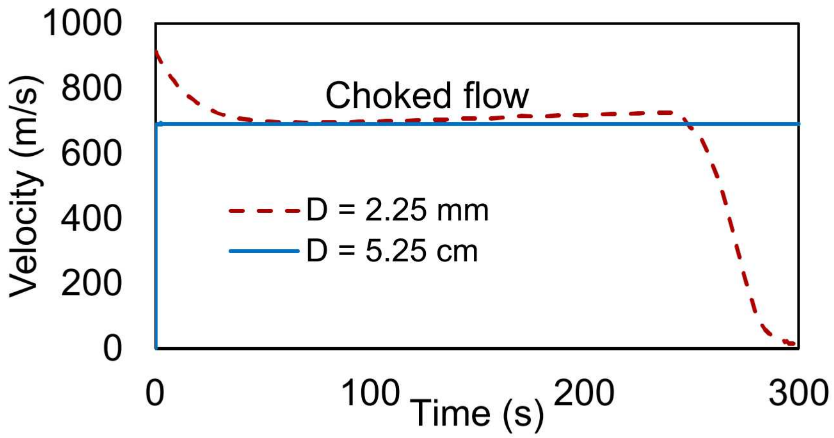
- Valve orifice diameter was adjusted due to mesh constraint
  - Actual valve diameter 2.25 mm → CFD orifice diameter 5.25 cm
  - Same mass flow rate by adjusting velocity under-predicts flame impingement duration on the ceiling

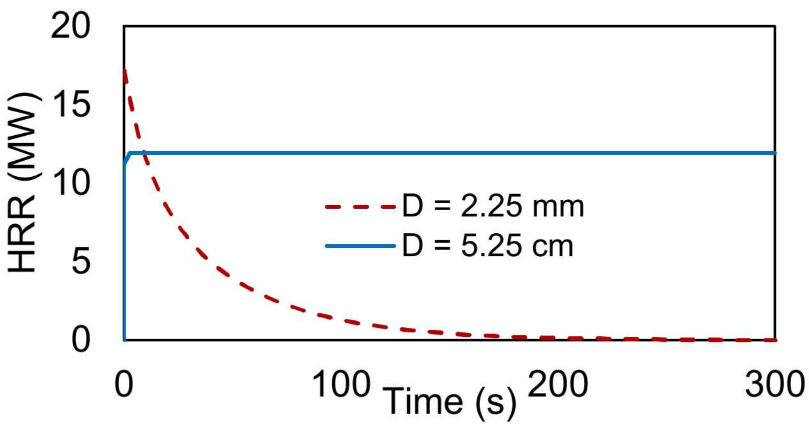


https://cafcp.org/emergency-responders

- 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,

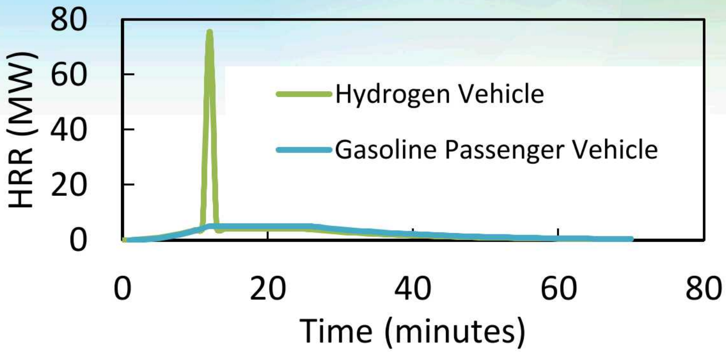
$$HRR = \dot{m}_0 \Delta H_c$$

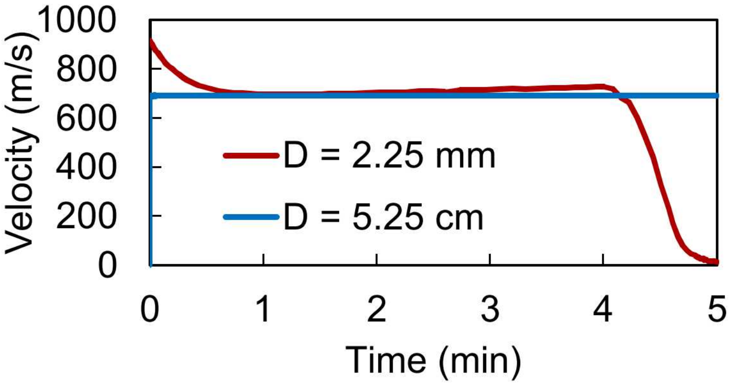


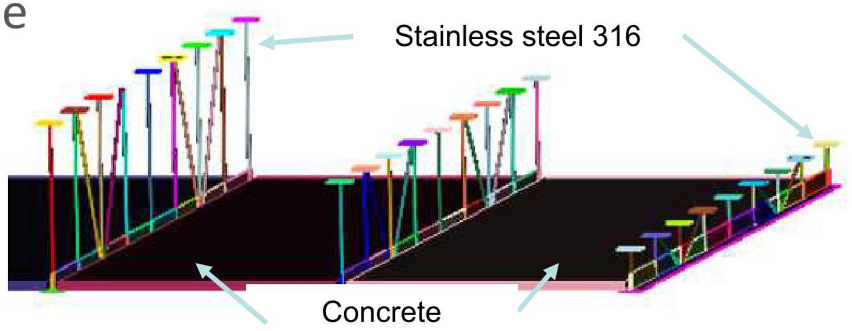


Important Conservative Assumptions

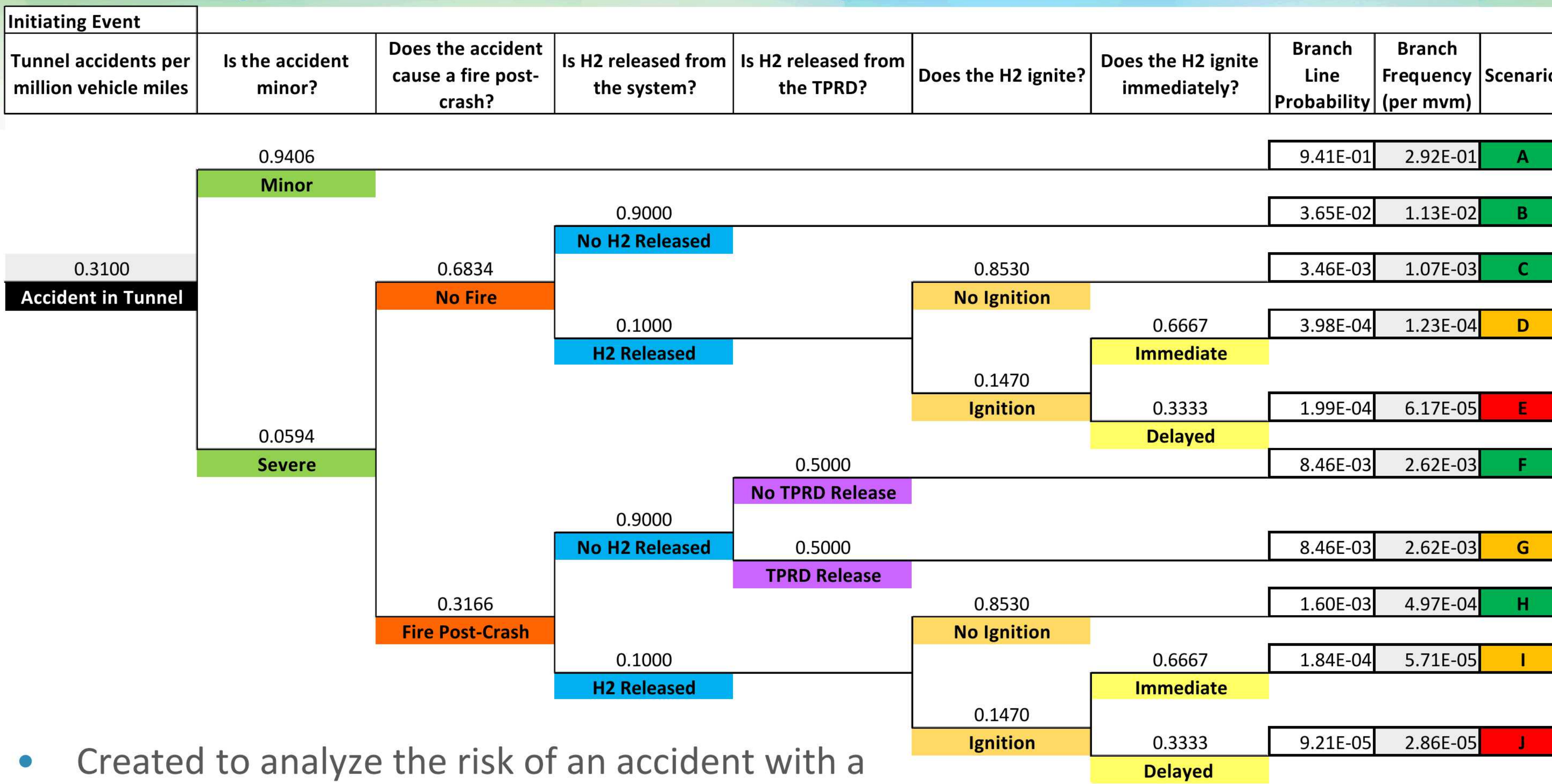
- Only one fuel can be burned at a time in the simulations
  - Simulations include only hydrogen jet flame
  - Heat Release Rate (HRR) from hydrogen is constant for the 5 minutes of the H_2 release
- Constant choked velocity was used for the release of hydrogen (no blowdown over time)
  - Blowdown would 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

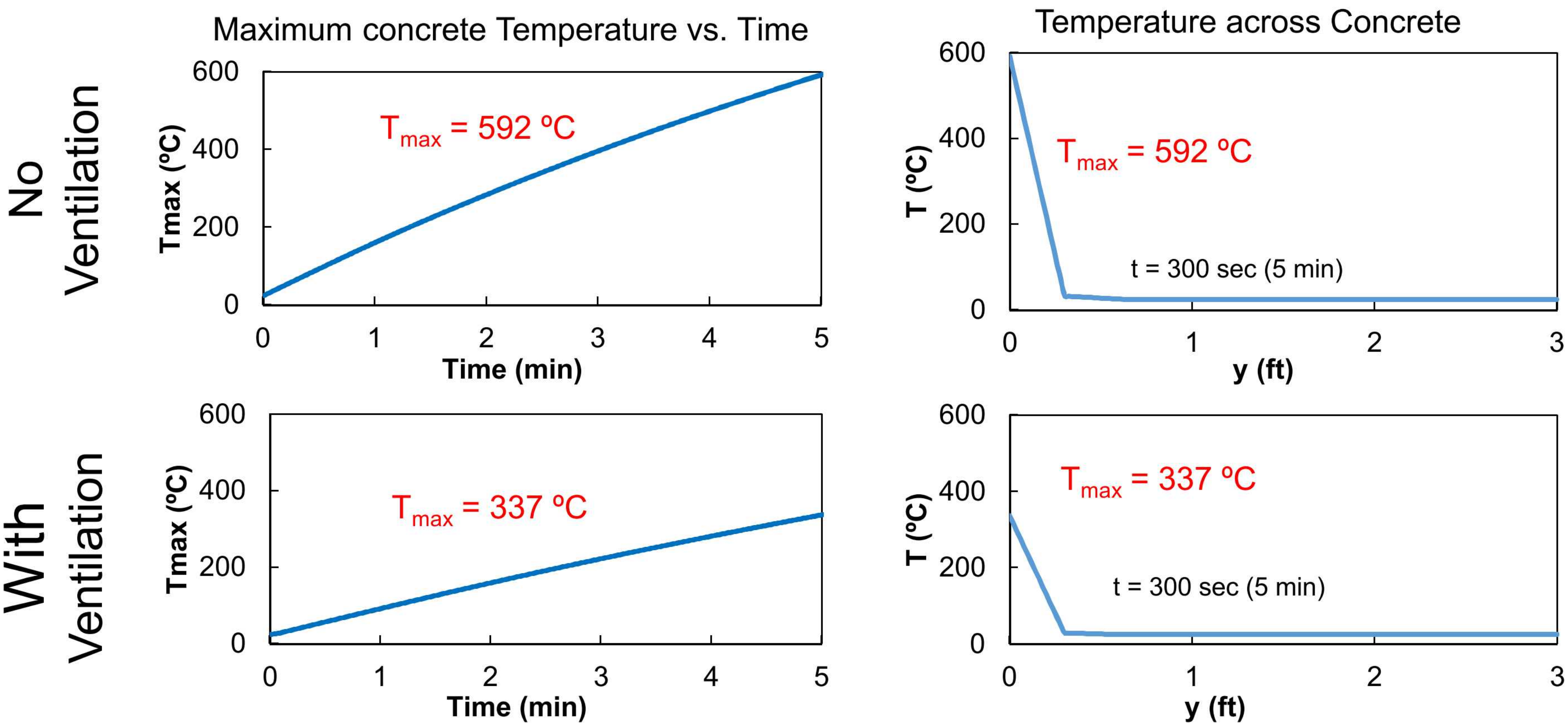


- Created to analyze the risk of an accident with a hydrogen fuel cell vehicle
- The event tree illustrates the chronological sequence of events involving the successes and/or failures of the system components

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

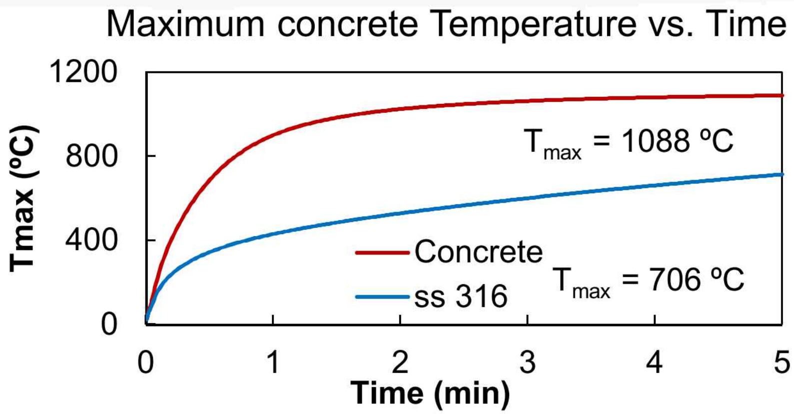


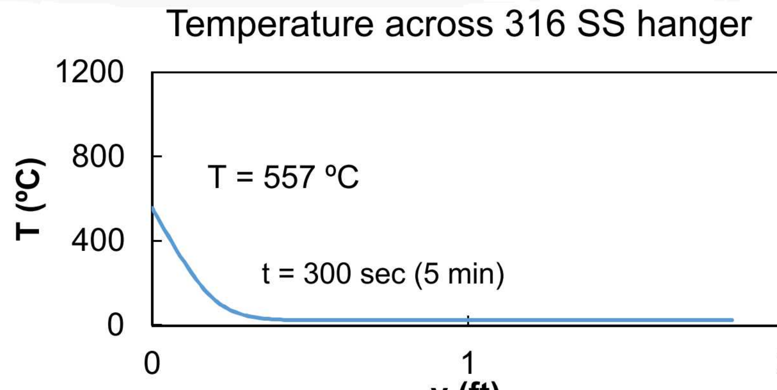
It is much less likely to have explosive spalling when tunnel ventilation is operating

Accomplishments: Effects on Structural Elements Predicted

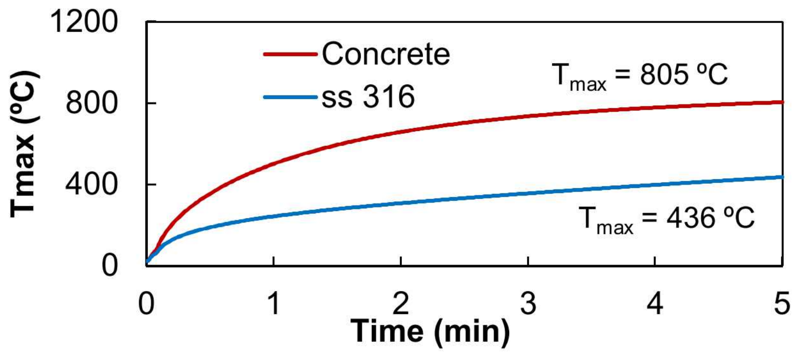
TW Tunnel

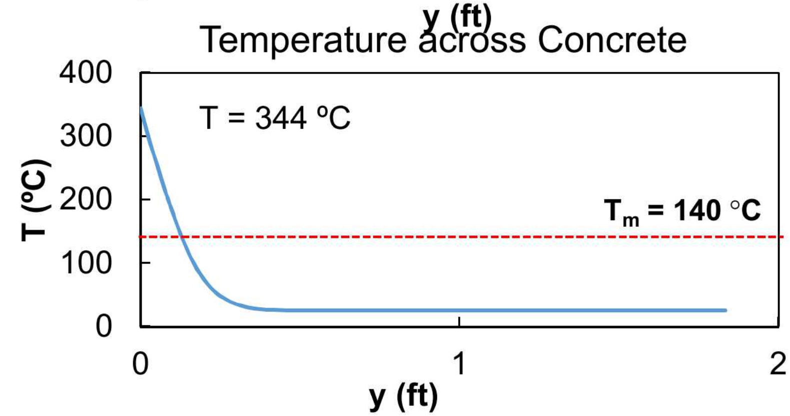
No Ventilation





With Ventilation





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