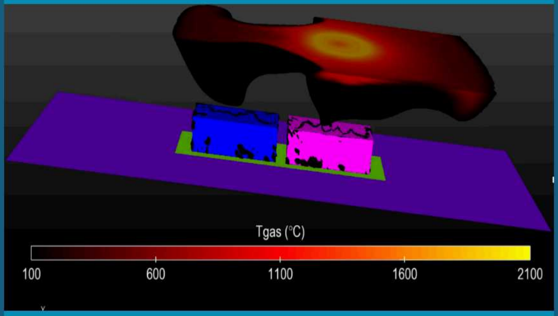
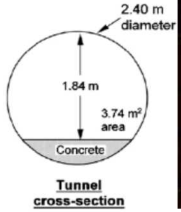
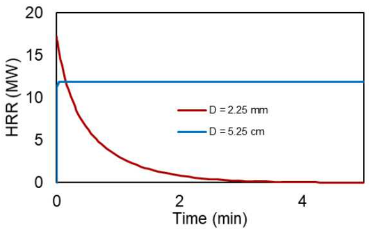
SAND2020-0277PE

Update on Alternative Fuel Vehicles







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AASHTO COBS T-20 Tunnel Mid-Year Meeting

January 14, 2020

SAND2020-xxxx PE

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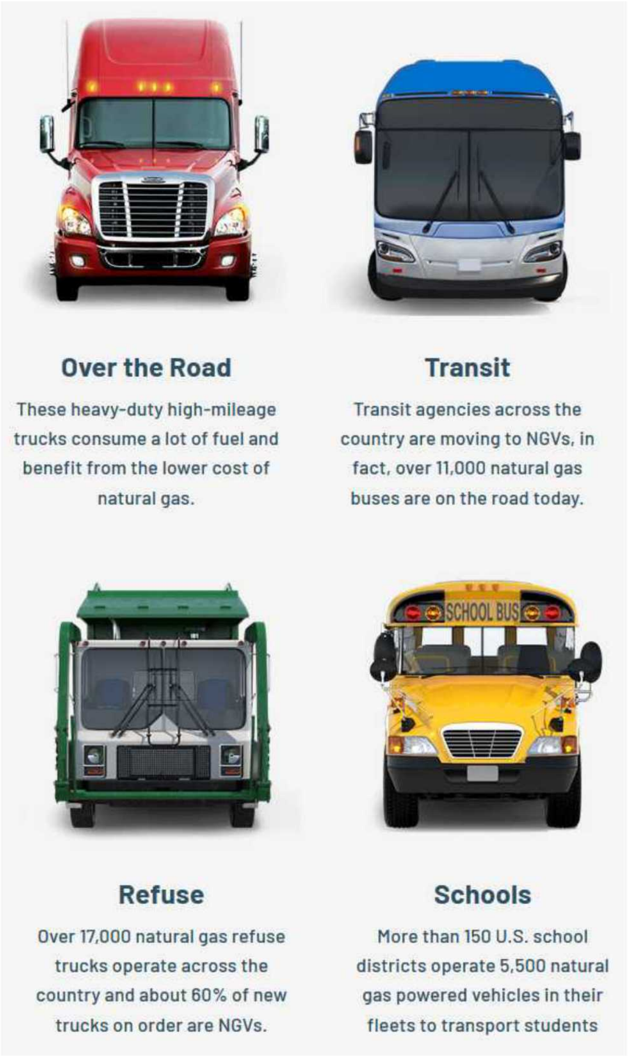
Background

Increasing numbers of alternative fueled vehicles are on the roads in the US

- Battery Electric Vehicles
  - Battery Electric vehicles sold in the United States reached nearly 240,000 in 2018, with sales of Tesla models accounting for around 80 percent of that figure. The combined sales of twelve other manufacturers made up the remaining 20 percent
  - https://www.statista.com/statistics/698414/sales-of-all-electric-vehicles-in-the-us-by-brand/
- Natural Gas Vehicles
  - Natural gas powers more than 175,000 vehicles in the United States and roughly 23 million vehicles worldwide.
  - There are more than 1,600 CNG and 140 LNG fueling stations in the U.S., and refueling appliances are available for home use
  - https://www.ngvamerica.org/vehicles/
- Propane Vehicles
  - According to the Propane Education & Research Council, there are nearly 200,000 on-road propane vehicles with certified fuel systems in the United States.
  - Many are used in fleet applications such as school buses, shuttles, and police vehicles
  - https://afdc.energy.gov/vehicles/propane.html



https://www.ngvamerica.org/vehicles/

Snapshot of Hydrogen and Fuel Cells Applications in the United States

Examples of Applications

>500MW
Stationary Power

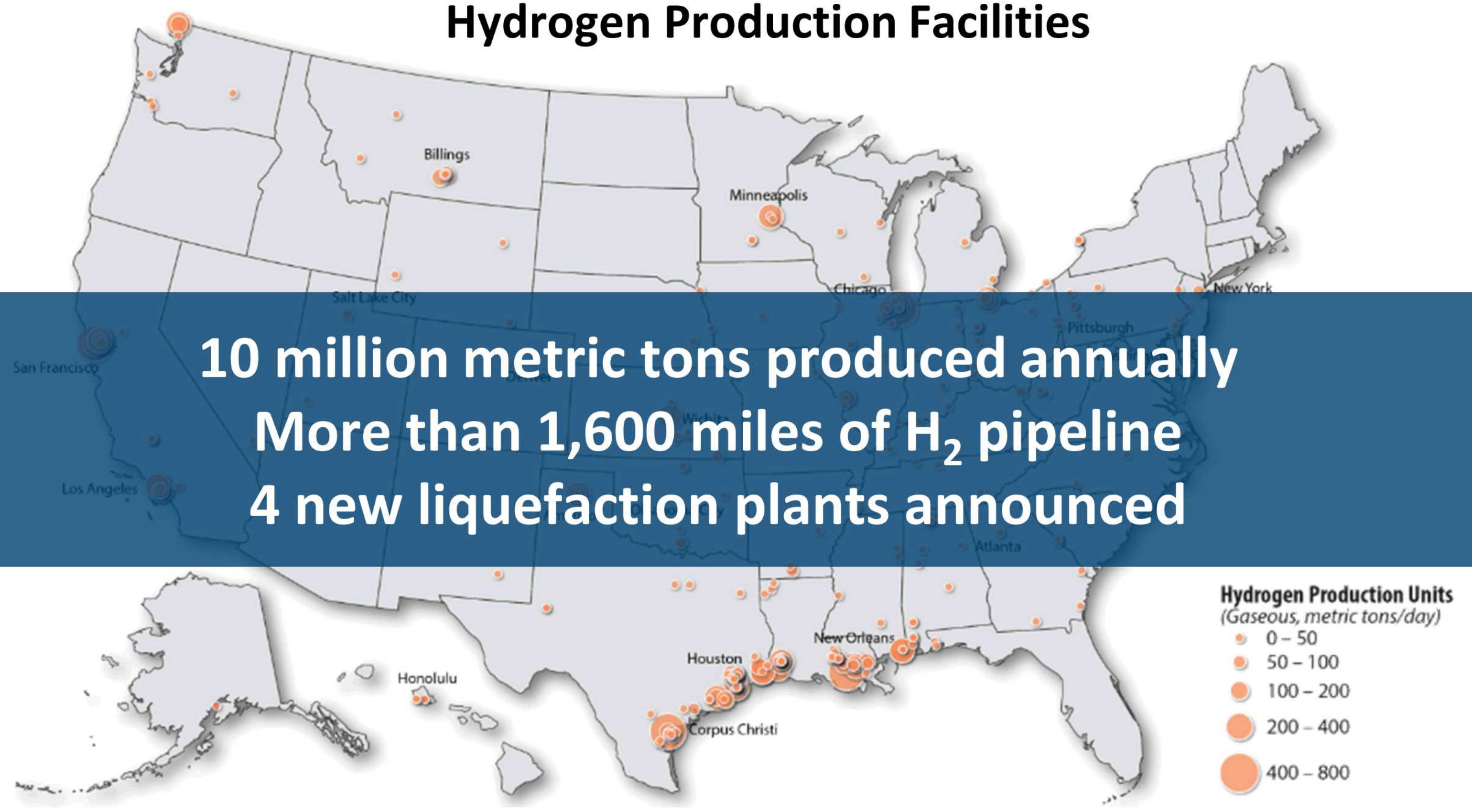
>28,000
Forklifts

>30
Fuel Cell Buses

>45
H_2 Retail Stations

>7,800
Fuel Cell Cars

Hydrogen Production Facilities



10 million metric tons produced annually
More than 1,600 miles of H_2 pipeline
4 new liquefaction plants announced

Hydrogen Stations: Examples of Plans Across States

California
1,000 stations by 2030 CAFCP goal

Northeast
12 – 20 stations planned

HI, OH, SC, NY, CT, MA, CO, UT, TX, MI, and others

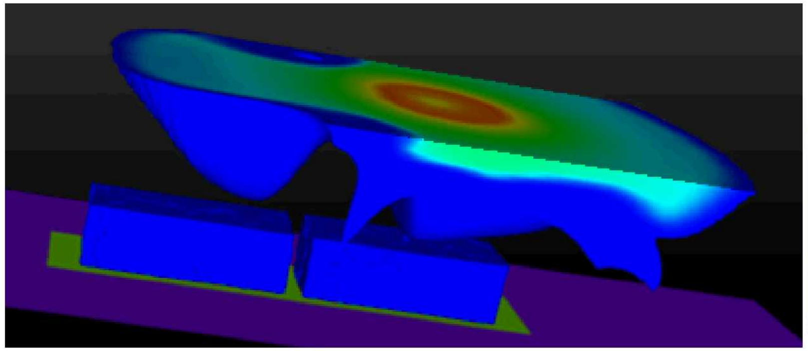
Tunnel Safety Progress to Date

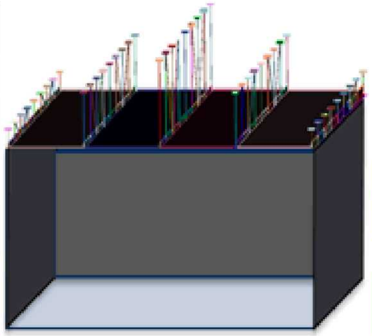
Conversations have taken place with region tunnel owners

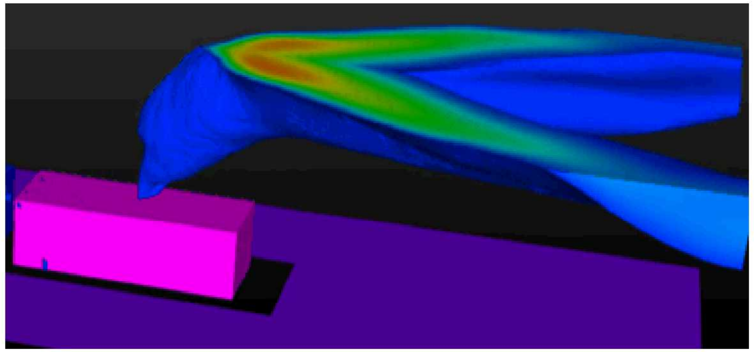
Dedicated individual studies have been conducted over the years for specific tunnels, especially for new construction

Detailed tunnel-specific evaluations are expensive and take years. In the meantime, more and more alternative vehicles are on the roads and using tunnels.

In order to provide meaningful solutions to these problems, a collaboration between DOE and DOT was initiated last year.







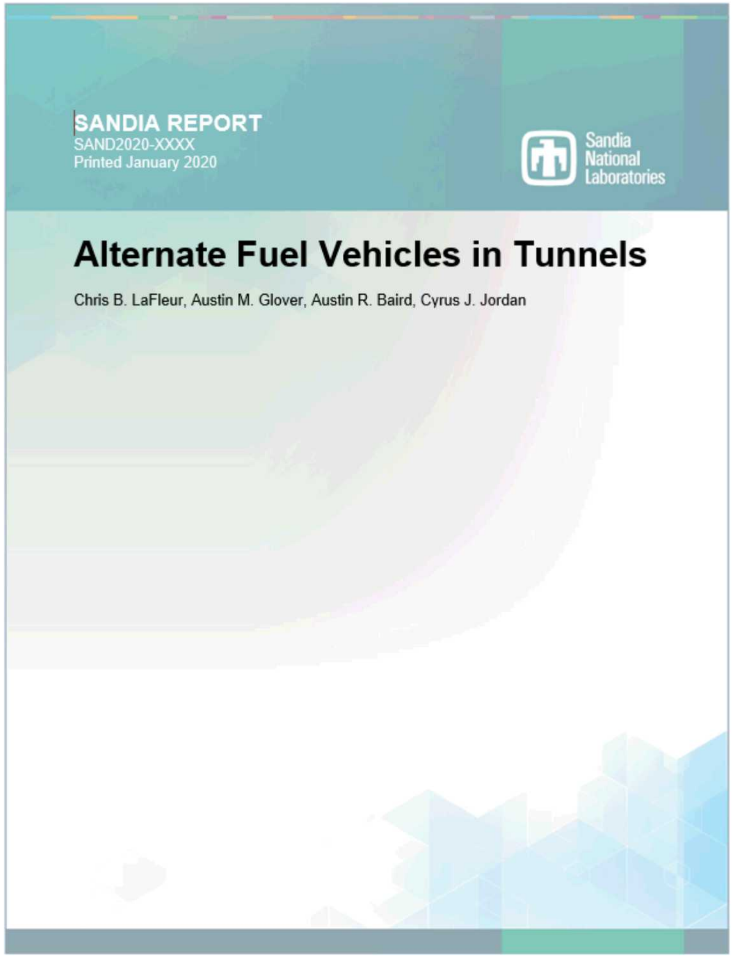
DOT/DOE Collaboration

https://energy.sandia.gov/programs/sustainable-transportation/hydrogen/quantitative-risk-assessment/

Joint effort to pave the way for FCEV access to tunnels nationwide instead of piecemeal

Plan Includes

- Assembling stakeholder group of tunnel owners and regulators in the US
- Addressing issues and knowledge gaps for all alternative fuel vehicles
- Developing report: Alternate Fuel Vehicles in Tunnels
  - Literature search of research in tunnels for:
    - Conventional fueled vehicles
    - Battery electric vehicles
    - Natural gas vehicles
    - Propane vehicles
    - Hydrogen fuel cell electric vehicles
  - Research gaps
- Reviewing and addressing concerns from stakeholders
- Identifying research projects to fill critical knowledge gaps



Literature Search

Goal: Capture the current research on each vehicle type as they relate to hazards in tunnels and begin to evaluate knowledge gaps

Research is grouped by type

- Experiments – Full and medium Scale
- Modeling – Detailed computational modeling that characterizes consequences of different hazard scenarios
- Analysis – Physics and energy balance equations utilized to evaluate hazard scenarios

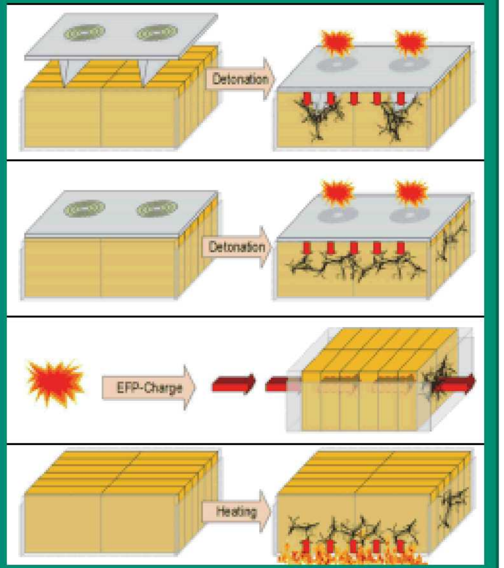
Plausibility of Hazard Scenarios

Battery Electric Vehicles (BEVs)

Major takeaways

- Identification of Scenarios and Failure Modes –
  - Bench scale level abuse testing has defined both cell level and module level scenarios that lead to a failure mode.
  - Vehicle scale scenarios have been observed in limited experiments, real world crash incidents, or vehicle failures.
- Consequences –
  - Limited vehicle-scale tests have been conducted
  - Variations in cell chemistry, capacity, thermal runaway propagation between cells, state of charge, form factor, and other variations affect hazards
  - Hazards associated with BEVs are not as well characterized as some of the other alternative fuel vehicles

1. **Wedge-Shaped Penetration**
2. **Blunt Impact**
3. **Central Puncturing**
4. **Thermal Stress**



Four test scenarios were evaluated to induce a fire. [Mellert 2018]

Conclusions and recommendations for research include:

- Better define the effect of cell/module chemistry, form factor, electrolyte composition, etc. on the consequence.
- Further study is needed at the larger scale, specifically around conditions that can cause thermal runaway causing vent gas production and fire spread between battery cells.
- Current BEVs are limited to light duty vehicles, but, medium- and heavy-duty BEVs will be developed and the fire, vent gas production, and toxic chemical release risks will need to be characterized.

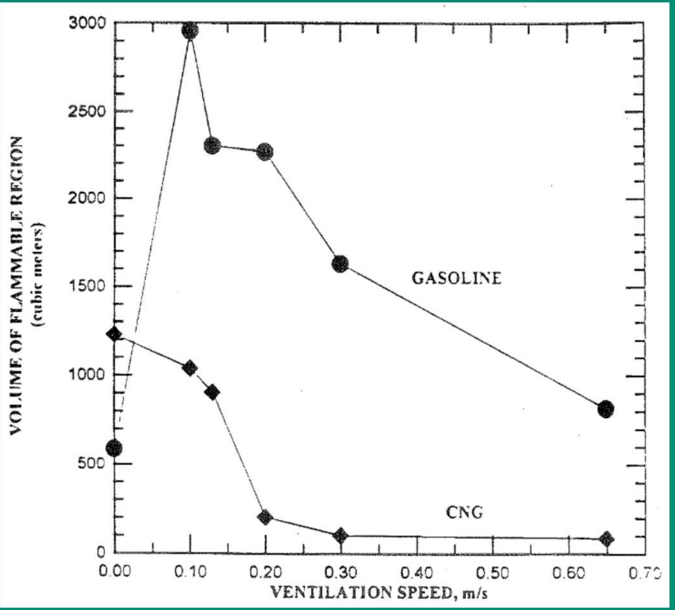
Natural Gas Vehicles (NGVs)

Major takeaways

- Identification of Scenarios and Failure Modes – multiple research studies have clearly defined failure scenarios and hazard analyses
- Consequences – Multiple experiments and modeling simulations have evaluated scenario consequences of NG in confined areas, but not specific to NG vehicles as a system

Conclusions and recommendations for research include:

- Evaluation of the risk of spalling of tunnel surface from flame impingement or heat from a NG jet flame.
- Experimental studies of NG dispersion and overpressure in actual or scaled down tunnels (similar to Hydrogen evaluations).
- Characterization of partially pre-mixed (realistic extents of pre-mixing) ignition in tunnels to determine maximum overpressure.
- Analysis of large scale NG flames heat transfer analysis. So far only lab-scale or simulated data found in the literature.
- Characterization of the hazards as the scale of vehicle increases for medium and heavy duty vehicles.



Volume of flammable region versus ventilation speed from simulation [Zalosh 1998]

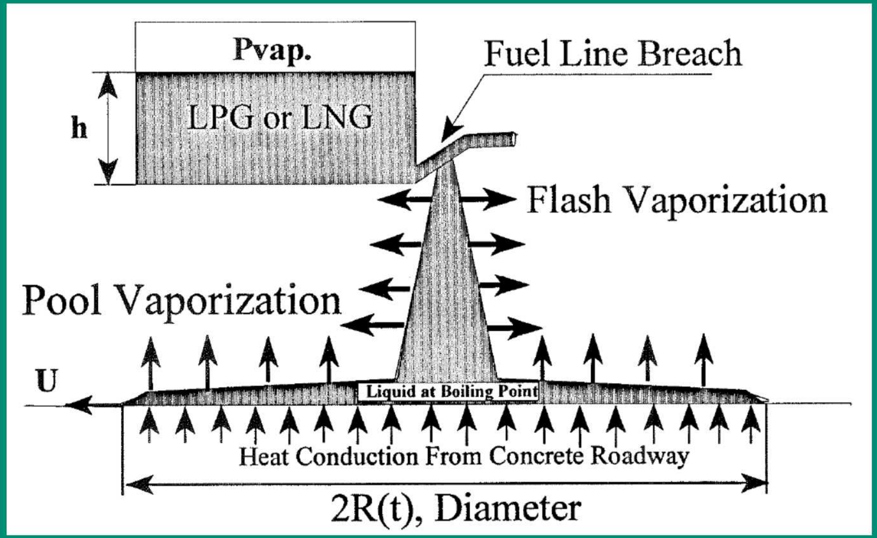
Propane Vehicles

Major takeaways

- Identification of Scenarios and Failure Modes – a probabilistic risk analysis identifying and evaluating scenarios for different fuels in a tunnel was preformed [Krupka 1983]
- Consequences – Modeling of the dispersion of propane [Zalosh 1998] and the explosive load for worst case concentration in a tunnel scenario [Pundkar 2012] were conducted

Conclusions and recommendations for research include:

- Conduct a more thorough evaluation of failure modes for propane vehicles of all sizes
- Evaluate the heat release rate, temperature, and structural damage resulting from different failure modes
- Evaluate the effect that overpressure and deflagration of released propane has on structural components of tunnels
- Evaluate the effects of ventilation, obstructions, and tunnel geometry on the consequence of failure modes

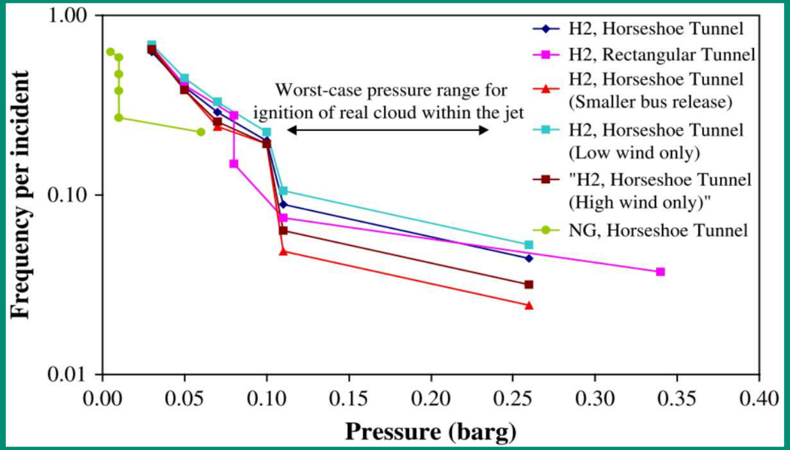


Relevant Phenomena in Mathematical Model of LPG Spill and Vaporization [Zalosh 1998]

Hydrogen Fuel Cell Electric Vehicles (FCEVs)

Major takeaways

- Identification of Scenarios and Failure Modes –
  - A scenario identification study was conducted that documented the risk significant initiating events in terms of hazards involving hydrogen FCEVs .
  - The failure modes with potentially hazardous consequences identified in the scenario identification effort included both immediate and delayed ignition of released hydrogen.
- Consequences –
  - Modeling and measurements of the consequences including overpressure, heat release rate, hydrogen dispersion, and resulting structural damage have been made to determine the extent of the hazard.
  - Comparison studies have been conducted between the modeling and experimental studies to validate the results.



Exceedance curves for overpressure values per fuel type [Middha 2009]

Conclusions and recommendations for research include:

- Conduct studies to understand how the increase of energy onboard affects the hazard as larger classes of vehicles are developed
- Improve characterization of the risks of hydrogen vehicles by reviewing the HyTunnel-CS project results in Europe which will reduce over-conservatism and increase efficiency and cost savings of tunnel and confined space safety systems
- Evaluate the effect of ventilation on the risk of spontaneous ignition in a tunnel
- Characterize the extent to which hydrogen can accumulate due to partial confinement and restriction, rather than complete confinement

Path Forward

Questions:

What scenario should be used to determine regulatory requirements?

What role should worst-case and implausible scenarios play in that determination?

Stakeholder group participation

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