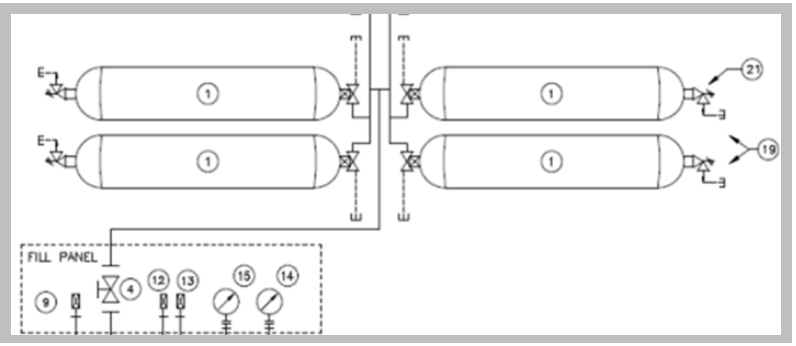
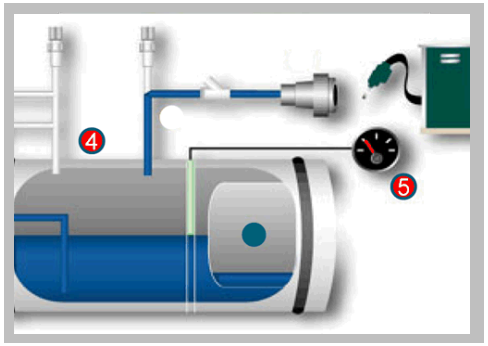
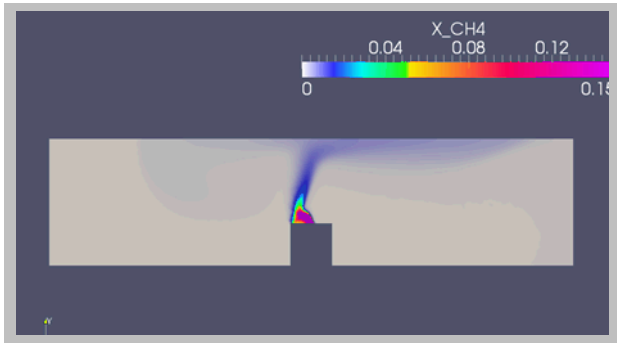
Gaseous Fuel Facility Analysis (Natural Gas and Propane Vehicles)

SAND2017-3589PE







PI: Myra Blaylock

Technical and Analytical Assistance for Clean Cities

Project Team: Rad Bozinoski, Brian Ehrhart, Ethan Hecht, Chris LaFleur, Alice Muña

Sandia National Laboratories

2017 DOE VTO Annual Merit Review

June 7, 2017

Project ID: TI078

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Overview

Timeline

- Project Start Date: Oct. 2016
- Project end Date: Sept. 2018*
  *Project continuation and direction determined annually by DOE
- 50% Complete

Budget

- FY16 DOE Funding: $250K
- Planned FY17 DOE Funding: $250K
- Total DOE Funds Committed to Date: $750K
- **$316K Spent (42%)**

Barriers

A. Availability of alternative fuels and electric charging station infrastructure.

D. Lack of technical experience with new fuels and vehicle technologies.

Partners

- Project lead: NREL
- Partner labs: NREL, ANL, ORNL
- Industry partner: NGVAmerica
- Expert Consultant: Doug Horne

Project Objectives

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Objective: Provide scientific modeling and analysis to resolve code conflicts and improve code requirements to enable alternative fuel deployment.

- Develop reduced-order engineering models of CNG/LNG /propane release behavior
- Evaluate key risk scenarios for maintenance facilities serving CNG/LNG vehicles in order to develop best practices and code revisions.
- Develop educational materials and inform code committees of risk mitigation strategies.

Barrier from 2011-2015 MYPP	SNL Impact
A. Availability of alternative fuels and electric charging station infrastructure.	Develop best practices for the updating and/or creating maintenance faculties for alternative fuel vehicles
D. Lack of technical experience with new fuels and vehicle technologies.	Build LNG/CNG-specific tools and analysis to enable code improvement and safety analyses to be based on strong science & engineering basis

Project Approach:

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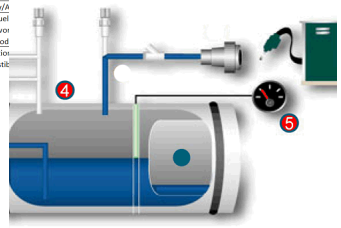
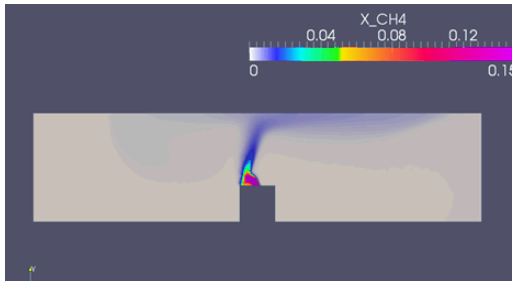
Facility Prevention, Detection & Mitigation Measures							
Prevention of Ignition Features				Detection Method	Mitigation of Ignition Features		
Design		Administrative			Design	Administrative	
1	Electrical classification areas	1	Operating procedures	1	Gas detection (LEL sensor)	1 Automatic emergency shutoff valve	1 Operating procedures
2	Grounding and bonding	2	Housekeeping (combustible material limitations)	2	Fire alarm detection	2 Manual emergency shutoff valve	2 Portable fire extinguisher
3	Non-combustible construction	3	Prohibit smoking	3	Person smelling smoke	3 Automatic fire suppression	
4	Constant ventilation	4	Clean parts with nonflammable solvent	4	Visual Flame	4 Fire barriers	
5	Interlock driven ventilation	5	Floors kept clean of oil and grease			5 Separation distance to exposures	
6	Flexible vent hose attachment to atmosphere	6	Combustible trash placed in covered, metal receptacles				
		7	Limit heat-producing appliances				
		8	Security/A				
		9	Purge fuel repair wor heat-prod				
		10	Separatio combusti				



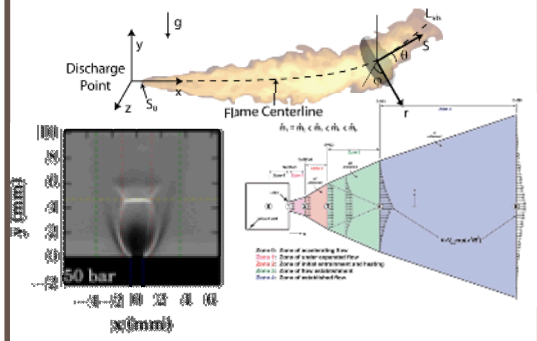
Develop risk analysis

for determining key, high-risk scenarios to further analyze



Apply risk analysis & behavior models to high risk scenarios

in alternative fuel infrastructure



Develop and validate scientific models

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

Enabling methods, data, tools for LNG/CNG safety

Scientific, Risk-Informed Process for Improving Codes & Standards

Project Approach

- Improve **codes and standards** for gaseous fuel vehicle **maintenance facility** design and operation to reflect technology advancements
- Develop **Risk-Informed guidelines** for modification and construction of maintenance facilities and use **Quantitative Risk Assessment** to identify most pressing scenarios to model
- Conduct **LNG validation experiments** and **model** the LNG releases to match the experiments
- **Leverage Sandia's expertise** and tools developed for FCTO SCS
- Continue to **identify risk scenarios** and **strengthen external collaborations** and partnerships

Milestones

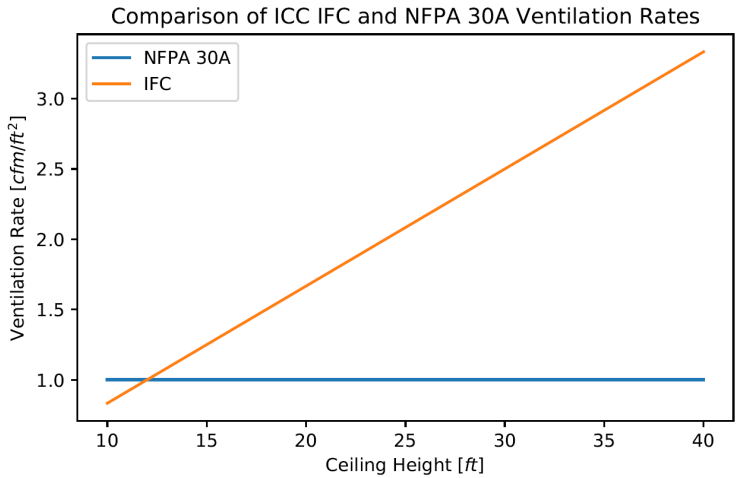
- Simulate LNG leaks in NGV facility
- Provide additional support information to next edition NFPA 30A and submit proposals to ICC code process in preparation for IFC and IMC
- Simulate PRD failure in NGV facility
- Best practices document

Future Milestones:

- Experimentally measure hazard properties of liquefied methane (LNG)
- Validate leak characteristic modeling with LNG experiment results

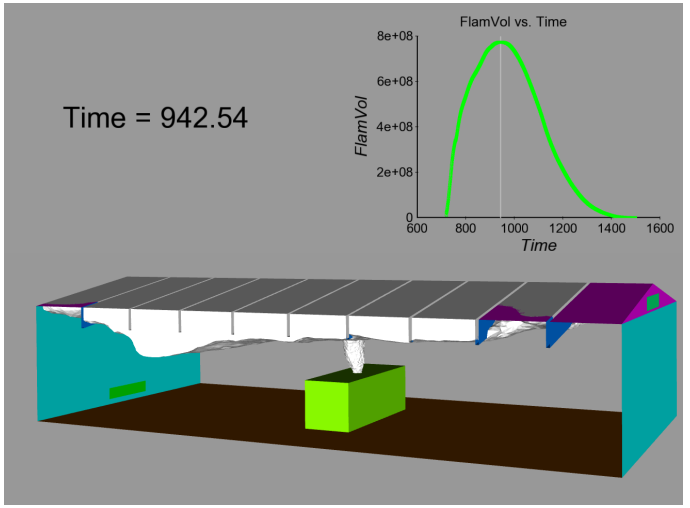
Project Accomplishments and Progress: Best Practices - NGV Repair Facilities

- Applicable safety codes and standards have been identified in both ICC and NFPA
  - Where code conflicts exist, most conservative code identified
  - Where code is unclear, best practices identified
- Focus on repair facilities for natural gas vehicles
- Invited and attended CSA code meeting Sept 29
  - NGV 5.2 Technical Subcommittee (NGV vehicle fueling appliances)



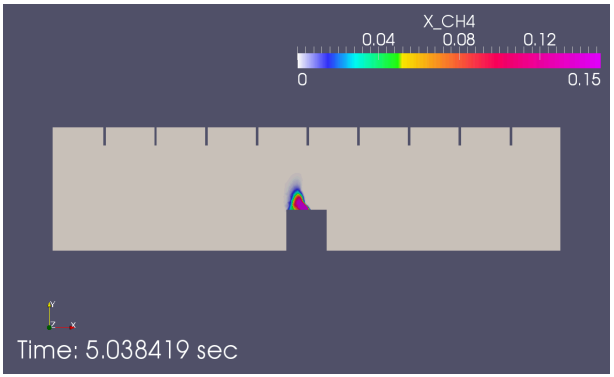
Project Accomplishments and Progress: Addressing Code Issues with Modeling

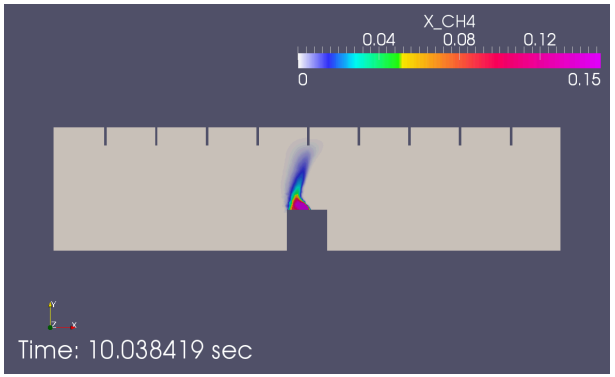
- NFPA 30A restricts sources of ignition from areas within 18” of ceiling
  - Based on legacy releases, does not cover all flammable concentrations
  - Modeling shows flammable concentrations outside of 18” area, so safety plan should be reassessed
- Proposal submitted for code change
  - Public Input No 25-NFPA 30A-2015
  - Remove hazardous location classification for area within 18” of ceiling since it is inadequate
- Additional modeling needed
  - CI-9-NFPA 30A-2015
  - Committee requests further modeling for various garage sizes and amounts of ventilation

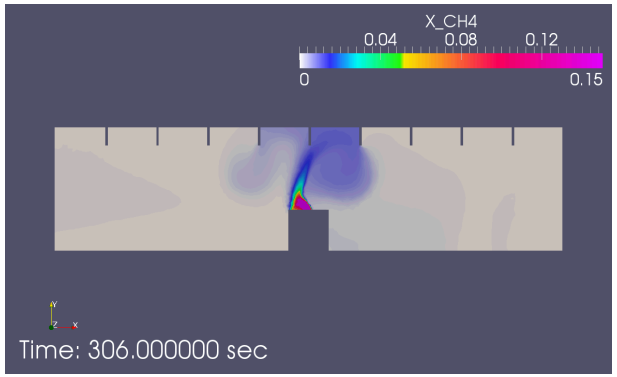


Project Accomplishments and Progress: Relaxing Requirements for De-Fueled Vehicles

- Additional safety requirements are in place for repair garages that perform maintenance on fueling systems
  - Proposing exceptions for repair garages that service CNG, LNG, H_2 if
    - Vehicles are purged with N_2 gas
    - Vehicles contain <250 psi NG
  - F273-16 to ICC IFC 2015
  - Voting occurred, waiting on final tally
- Additional computational modeling to assess safety of low pressure NG releases is underway







Project Accomplishments and Progress: Network Flow Modeling

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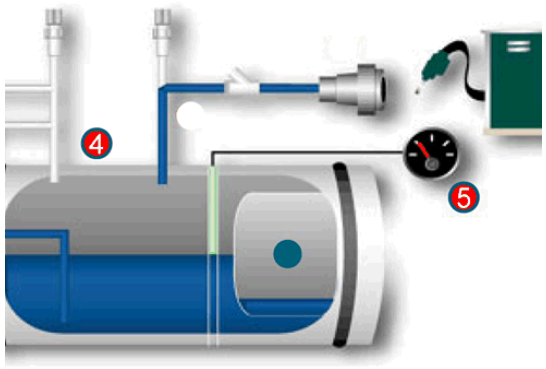
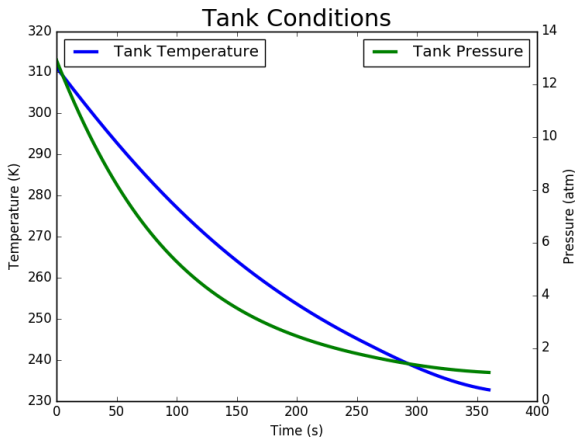
Fast transient system analysis

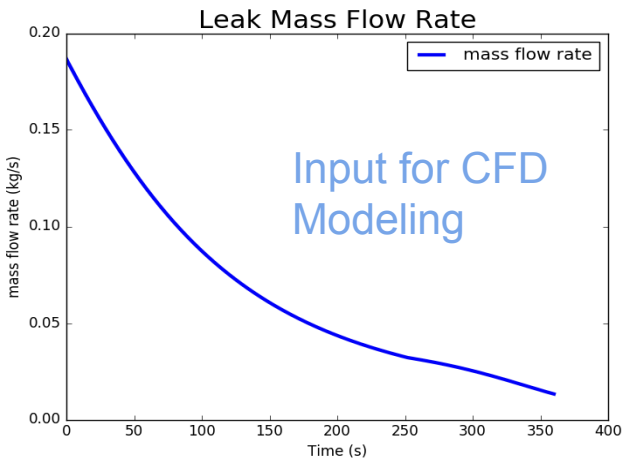
- Models venting/leaks of complex CNG/LNG tank and tubing systems



Generates leak input boundary conditions for CFD modeling



Calculates time required for tank to empty

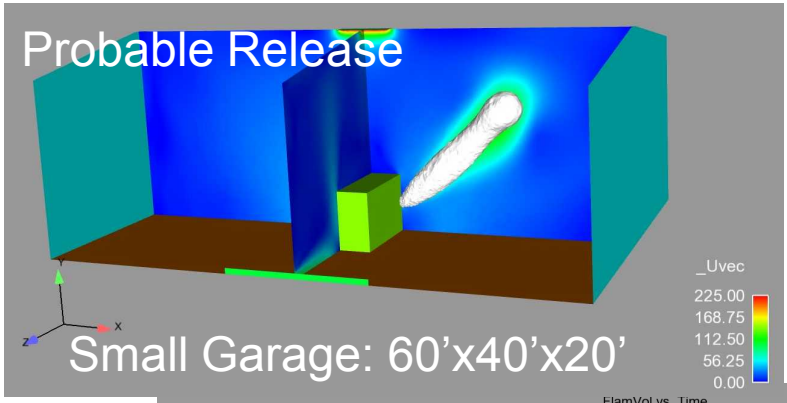


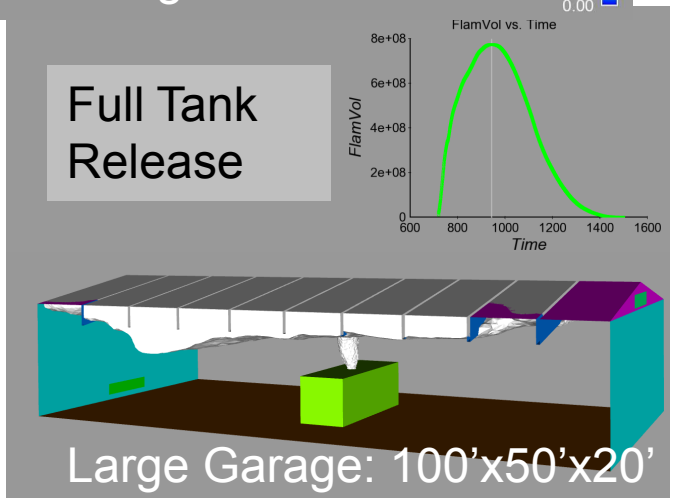
Project Accomplishments and Progress: CNG Modeling

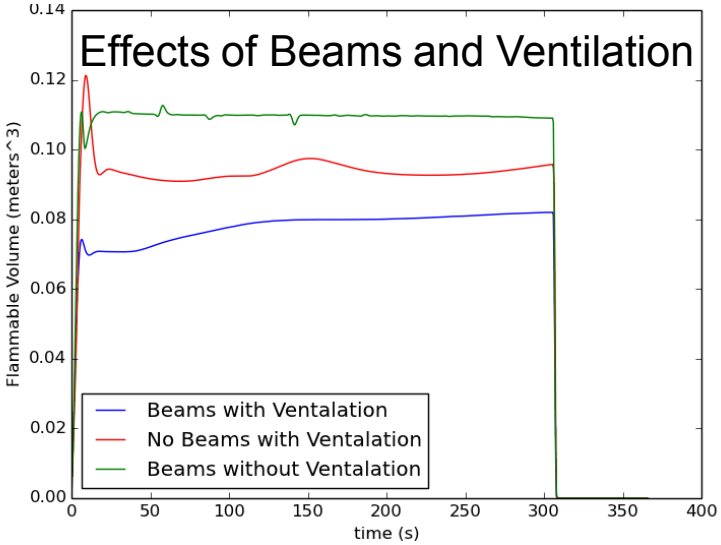
Computational Fluid Dynamics (CFD) is used to model leak scenarios in maintenance garages.

Scenarios were varied by:

- Two sizes of garages
- Leak location and amount
- Presence of ceiling beams: no significate difference
- Ventilation: reduces but doesn't eliminate flammable concentrations



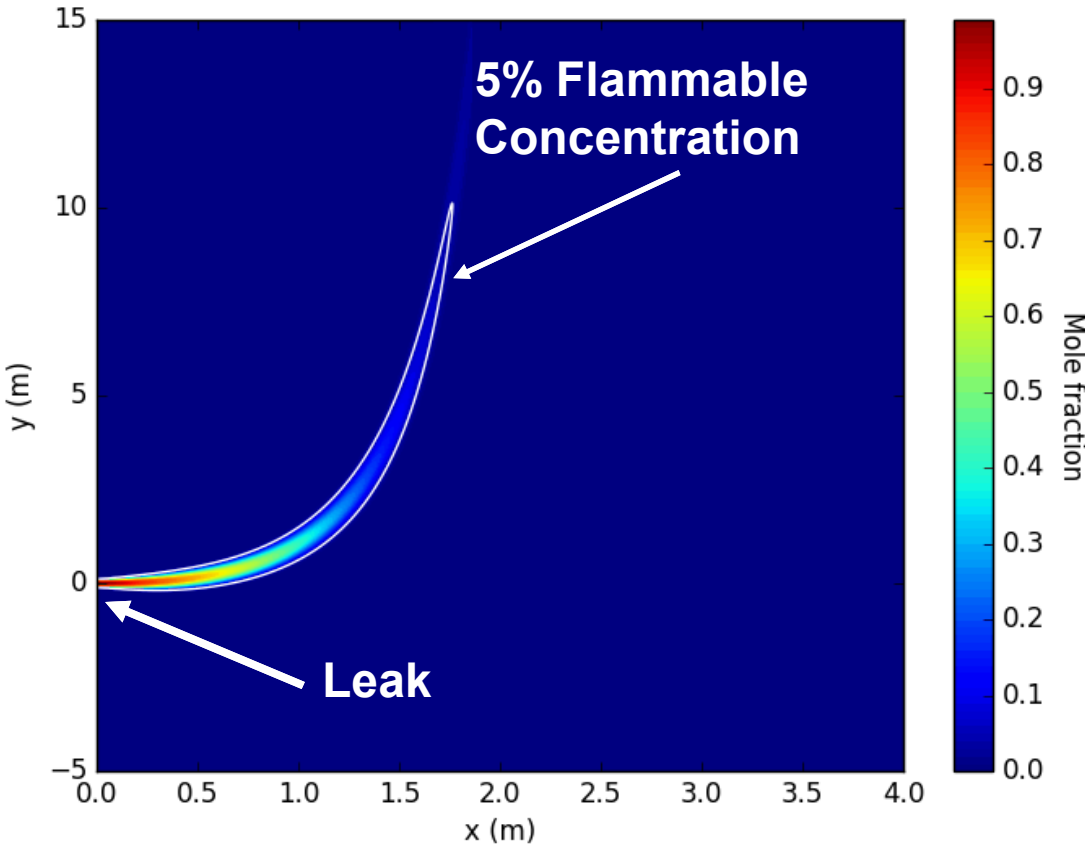




Results indicate that flammable concentrations can occur in regions not protected by NFPA 30A (lower than 18" from the ceiling).
Results can be used to assess sensor placement.

Project Accomplishments and Progress: Cold Plume Modeling

- Fast 2D modeling leak scenario release characteristics showing buoyancy effects and plume concentrations to initial estimate of flammable concentration locations
- Expanded on previously existing CNG plume model for LNG cryogenic releases. Leaks can be from either saturated liquid or vapor location of tank.
- Outflow leak conditions taken from Network flow modeling



Responses to Previous Year Reviewers' Comments

- This is this project's first review, so we have no comments from last year.

Collaboration and Coordination

- Presented at the Natural Gas Vehicle Technology Forum in San Diego, Oct 2016
  - Organized by NREL and involving many members of the NGV community
- Members of the NGVAmerica Technology Committee Maintenance Facility Working Group
  - Presented a Webinar during the WG's telecom
  - Attended and presented work at the in person meeting in June, 2016
- Actively consult with Doug Horne, a long time industry expert
- SNL's team members include experts in risk assessment, SCS, modeling, and cryogenic experimentation
  - This diverse team allows us to effectively understand and address issues with existing codes and standards
- Regular updates, both written and verbal, with VT sponsors

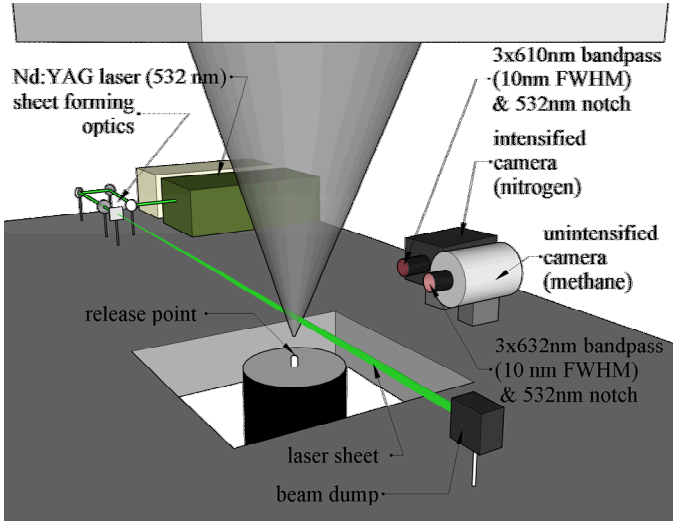
Market Impact and Sustainability

- Ensuring that construction of new or re-fit of existing repair garages for natural gas vehicles is based on scientific-based analysis that justifies safety features
- Highlighting and resolving potentially confusing and conflicting codes and standards for NG repair garages

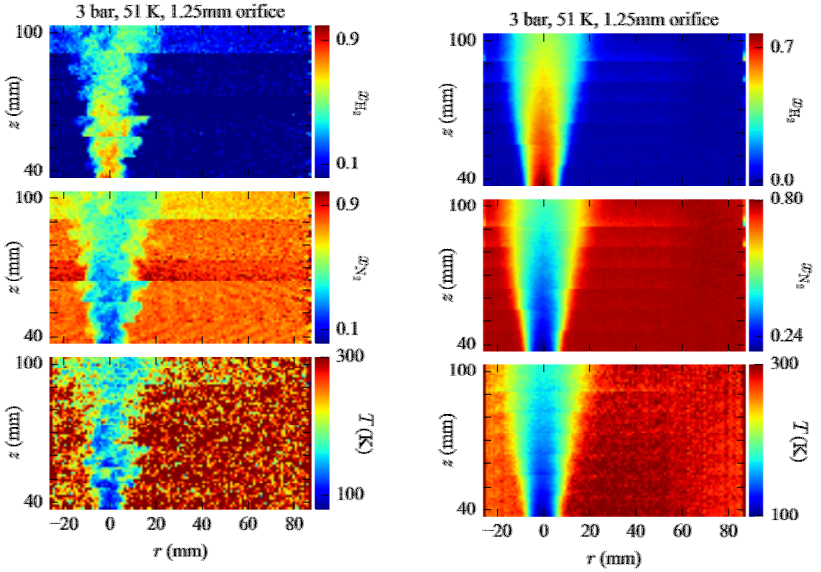
Proposed Future Research for End of FY17 and FY18

LNG experiments for understanding leak behaviors and model validation

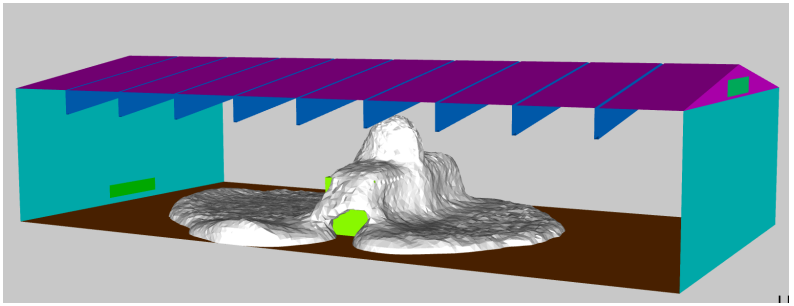
Experimental setup for liquid CH_4



Example cryogenic H_2 data



Preliminary CFD modeling of LNG scenarios shows flammable region initially near the ground. This will have implications on hazardous classified area locations.



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

Additional Opportunities

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Motivation: Establish a process to aide risk and modeling based informed decision making for codes and standards members

- Leverage our expertise with hydrogen vehicle infrastructure to other NGV areas beyond maintenance facilities
  - Safe design of fueling stations
  - Understanding risks of NGVs driving in tunnels to inform appropriate safety restrictions
  - Setback distances for LNG
- Develop modeling for other alternative fuels such as propane

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

Summary

- Using scientifically rigorous analysis and modeling to provide technical assistance to DOE, Clean Cities stakeholders , and end-users to address these technical challenges and bring advanced transportation technologies to market using Sandia's depth in applied science and engineering.
- Supporting Natural Gas Safety Codes and Standards
  - Provide scientific modeling and analysis to resolve code conflicts and improve code requirements to enable alternative fuel deployment.
  - Submitted changes based on risk assessment and modeling to NFPA 30A to modify hazardous classification locations
  - Supplied supporting modeling results to changes summited by NGVAmerica to IFC
  - Engaging with CSA at NGV 5.2 TSC meeting
- Developed models that incorporate physics of cold liquids and gasses to accurately predict LNG behavior
- Engaging with NGV community for input and direction of studies

Technical Back up slides

- Max 5 Slides

Modeling

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Analytical Modeling

- Fast, analytical models to predict leak velocities, temperatures, and plume shapes
- 1D Network flow solver
- Cold Plume: Notional Nozzle Model with buoyancy effects. Capable of modeling fuel as cryogenic liquid.

CFD Modeling

- More accurate representation of leak behavior, incorporating ventilation and room geometries
- 3D Reynolds Averaged Navier-Stokes (RANS) solver (SNL's Sierra-Fuego): finite volume, k-ε turbulence model, isothermal-slip walls

Technical Backup Slide: HAZOP Risk Assessment

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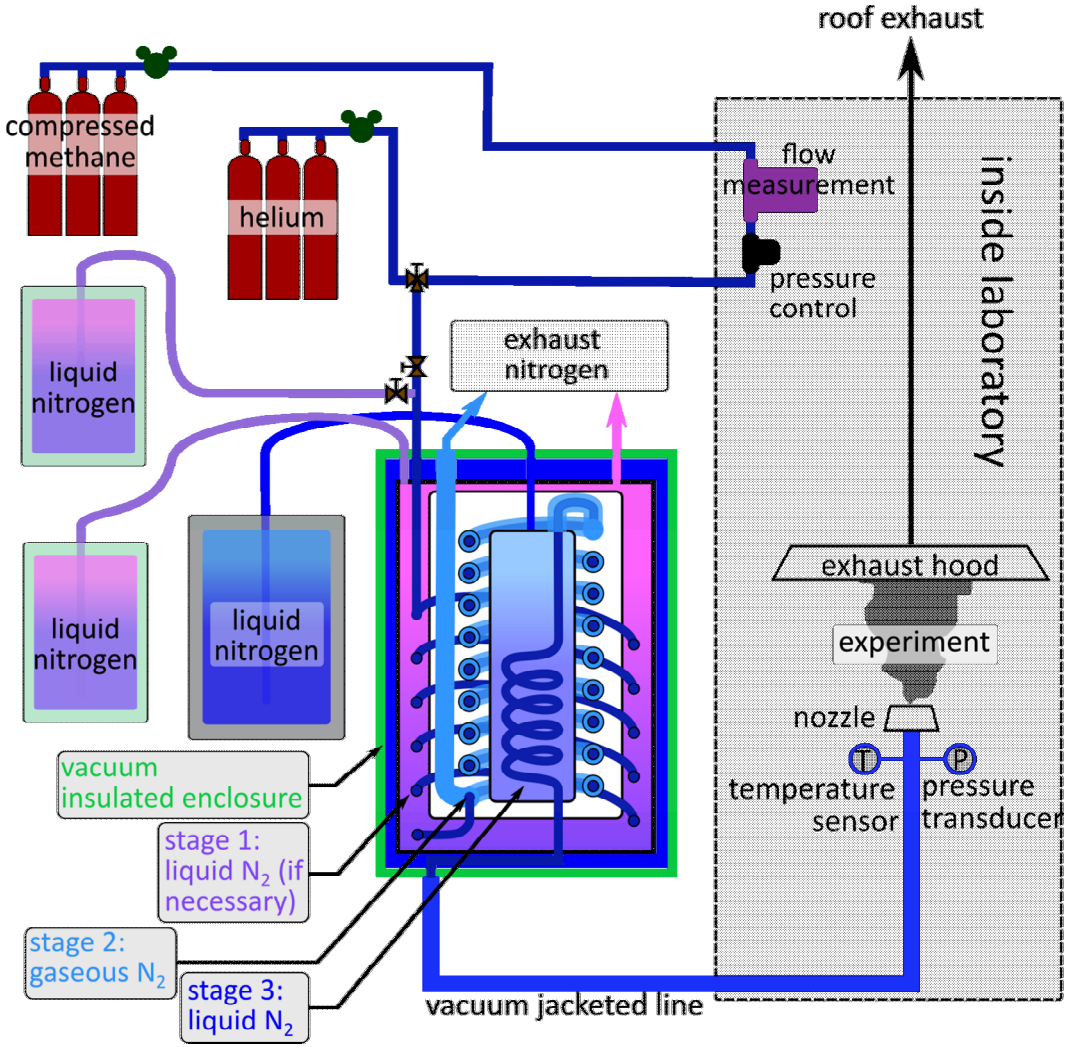
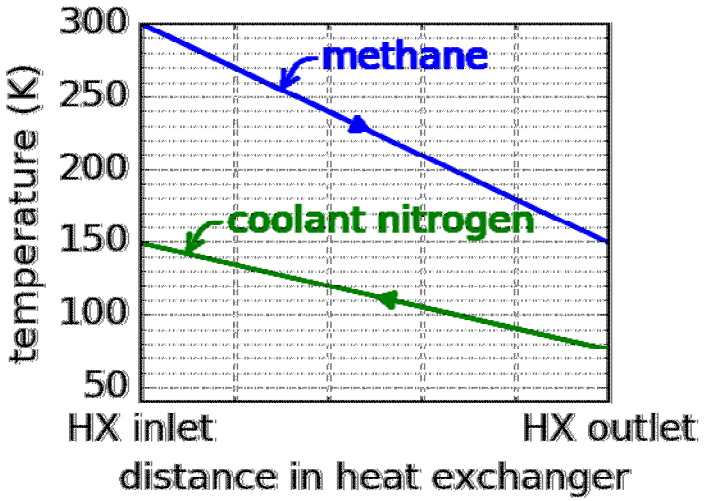
HAZOP Number	Component	Operation State	Hazard Scenario	Causes	Consequences	Consequence Class	Probability Class	Escalation
1	LNG-1 (Over pressure regulator)	3in, 4, 7, 8	External leakage from regulator body	Seal failure, mechanical defect, damage, etc.	Minor leakage of GNG	1	4	L
7	LNG-4 (LNG tank)	3in, 4, 5, 7, 8	Over pressure of tank and proper operation of relief valve	Excessive hold time, insulation failure	Minor release of GNG	1	5	L
12	LNG-5 (Pressure relief valve)	3in, 4, 5, 7, 8	Failure of PRV to reclose after proper venting, fails open	Mechanical Failure	Total volume of tank released	3	4	H
14	CNG-1 (Cylinders)	3in, 4, 5, 7, 8	Overpressure of Cylinder due to an External Fire	External fire AND successful operation of PRD	Potential catast-rophic release of CNG	3	2	H
15	CNG-1 (Cylinders)	3in, 4, 5, 7, 8	Outlet or fitting on tank fails	Manufacturing defect or installation or maintenance error	Potential catast-rophic release of CNG	2	3	H
19	CNG-3 (Pressure Relief Device)	3in, 4, 5, 7, 8	PRD fails open below activation pressure	Mechanical defect, material defect, installation error, maintenance error	Potential catast-rophic release of CNG	2	4	H
35B	CNG-20 (Tubing)	8	Leakage from tubing	Mechanical damage, material failure, installation error	Potential release of CNG	3	4	L
37	Multiple	Multiple	Human error or disregard for maintenance procedures	Procedures violated (Gas train not emptied, tank not isolated)	Total volume of system released	3	3	H

LNG Experimental Setup





- Accurate control/measurement of boundary conditions

Reviewer Only Slides

- No Limit

Publications and Presentations

- http://altfuels.sandia.gov

- "Analysis of a Full Scale Blowdown Due to a Mechanical Failure of a Pressure Relief Device in a Natural Gas Vehicle Maintenance Facility" by Myra Blaylock, Radoslav Bozinoski, and Isaac Ekoto. Sandia National Laboratories, May 2016. SAND2016-4534.
- Presentation at the NGV Technology Forum, October 18 and 19, 2016, in San Diego, California, by Myra Blaylock Sandia National Laboratories, 2016. SAND2016-10561 PE.
- Presentation at the NGV America Technology Committee Maintenance Facility Working Group, by Myra Blalock, Sandia National Laboratories, 2016. SAND2016-5842 PE

Critical Assumptions and Issues

- Assumption: Safety Codes and Standards Committees will find risk-informed, scientific, physics-based fluid dynamics models acceptable for code development and revision.
  - Solution: Remain engaged with committees and address concerns as they arise.
- Issue: The validation of the LNG releases hinges on the experiment yielding useable results.
  - Solution: Several data collection options are being considered if there are issues with the primary one.