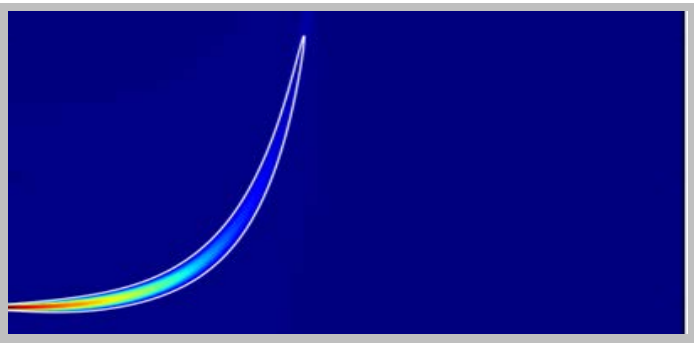
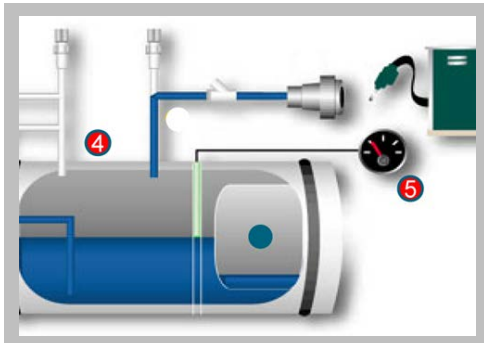
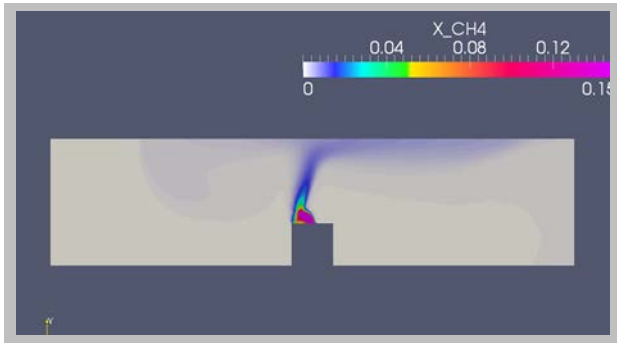
Gaseous Fuel Facility Analysis (Natural Gas and Propane Vehicles)







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

- Three years funded at $250K each
- FY16 DOE Funding: $250K
- FY17 DOE Funding: $250K
- **$74K Spent (30%) for FY17**

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, SNL
- Industry partner: NGVAmerica
- Expert Consultant: Doug Horne, a leader in NGV codes and standards development

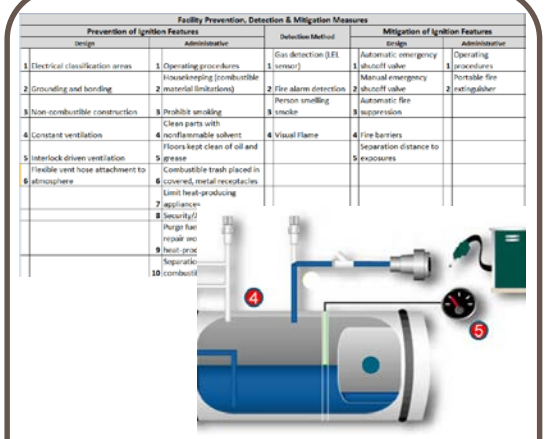
Project Objectives:

Sandia National Laboratories

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

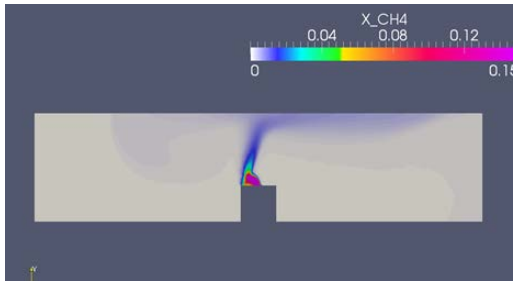
2016–2020 EERE STRATEGIC PLAN and Implementing Framework ***Goal 1: Accelerate the Development and Adoption of Sustainable Transportation Technologies***	
VT Deployment Strategies to address Goal 1: (Reducing Market Barriers)	SNL Impact
Provide Best Practices, Objective Data, and Informational Materials to Potential End-Users and Investors to Promote Acceptance of Advanced Vehicles and Alternative Fuels	Develop best practices for updating and/or creating maintenance facilities for alternative fuel vehicles
Support the Development and Harmonization of Codes and Standards	Evaluate key risk scenarios for maintenance facilities serving CNG/LNG vehicles in order to develop best practices and code revisions.
Address Alternative Fuel Infrastructure Deployment Challenges through Analysis	Build LNG/CNG-specific analysis tools to enable science & engineering based code improvement and safety analyses

Project Approach:



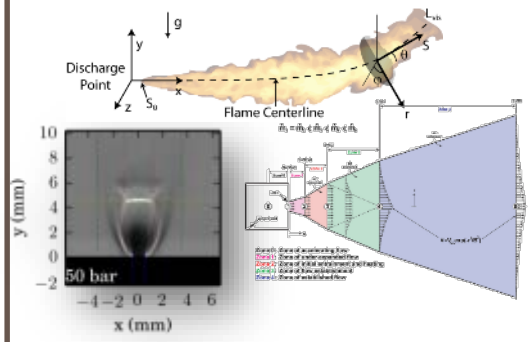
Develop risk analysis

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

- **Leverage Sandia's expertise in risk assessment, modeling, and experimentation** and apply to issues in alternative fuel infrastructure
- Develop **Risk-Informed guidelines** for modification and construction of maintenance facilities and use **Quantitative Risk Assessment** to identify most pressing scenarios to model
- Use both fast analytical as well as more thorough **computational modeling** to assess high risk leak scenarios
- Conduct **LNG validation experiments** and **model** the LNG releases that match the experiments
- Continue to **strengthen external collaborations** and partnerships to help **identify high risk scenarios** and make an impact in the field

Milestones

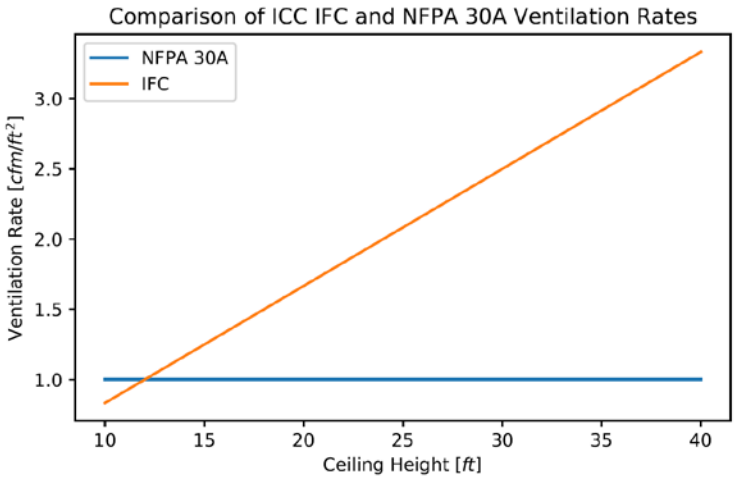
- Simulate LNG leaks in NGV facility to compare to CNG releases
- Provide additional support information to next edition NFPA 30A and submit proposals to ICC code process in preparation for IFC and IMC
- Simulate PRD failure in NGV facility to quantify amount and location of flammable release
- Best 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

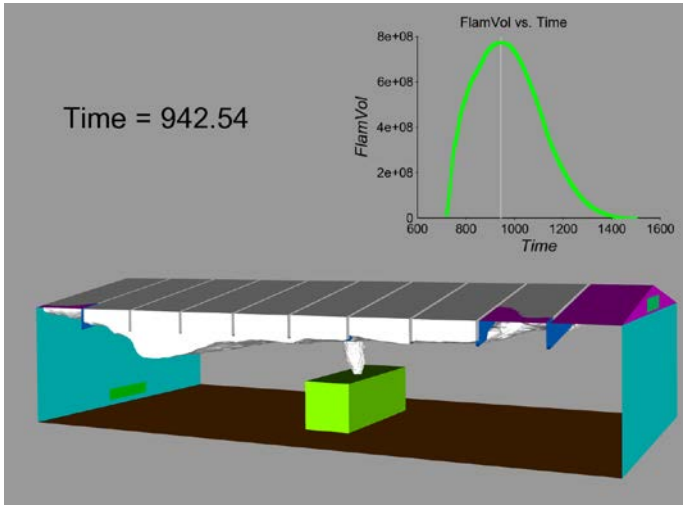
- Applicable safety codes and standards have been identified in both ICC and NFPA
  - Where code conflicts exist, most conservative code identified
  - Where code is unclear, best practices identified
- Focus on repair facilities for natural gas vehicles
- Invited and attended CSA code meeting Sept 29
  - NGV 5.2 Technical Subcommittee (NGV vehicle fueling appliances)
- HAZOP study identified which scenarios are most critical to alleviate and understand better through simulations



Provided data towards identifying, clarifying, and resolving code conflicts
Identified high risk leak scenarios

Project Accomplishments and Progress: Addressing Code Issues with Modeling

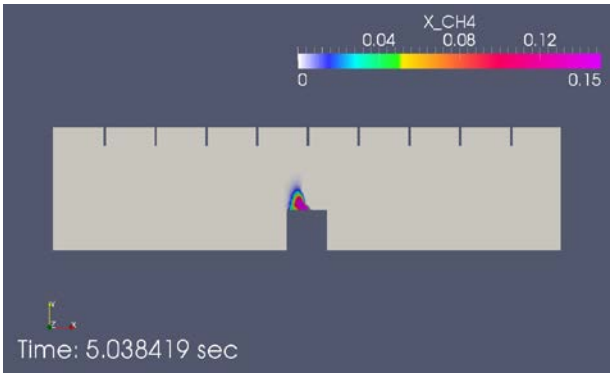
- NFPA 30A restricts sources of ignition from areas within 18” of ceiling
  - Based on legacy releases of gasoline, does not cover all flammable concentrations
  - Modeling shows flammable concentrations outside of 18” area, so safety plan should be reassessed
- Proposal submitted for code change
  - 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

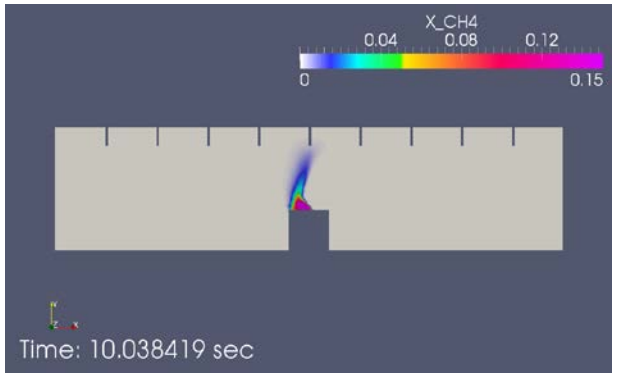


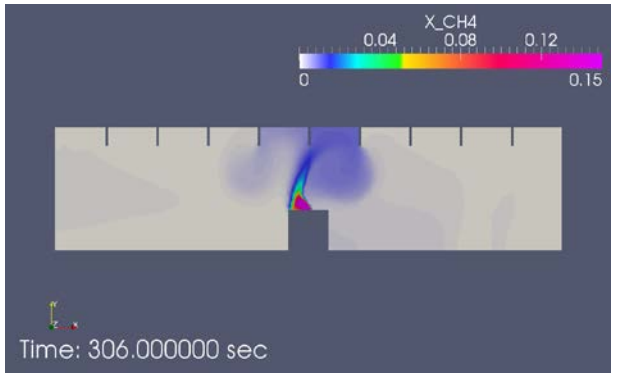
Modeling demonstrates that simple ceiling stand-off distance does not capture hazardous areas

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 compare de-fueled (<250 psi) NG releases to a full tank release is underway







Project Accomplishments and Progress: Network Flow Modeling

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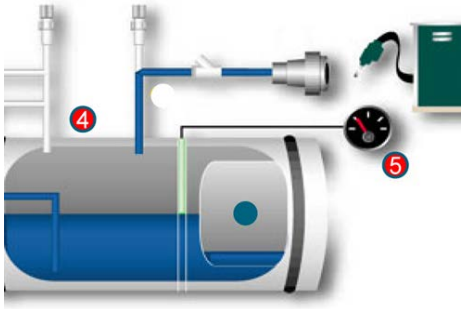
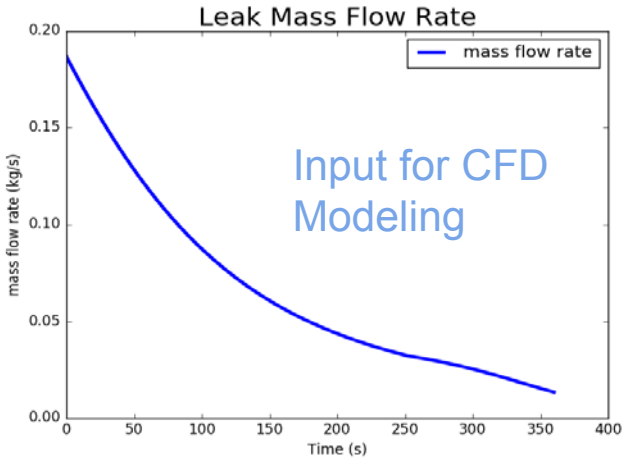
Fast transient system analysis

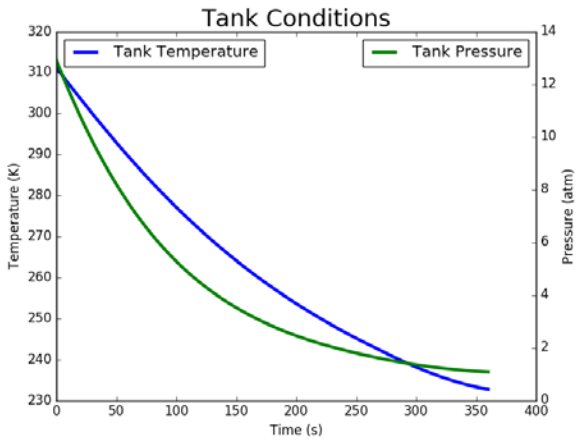
- Models venting/leaks of complex CNG/LNG tank and tubing systems
- LNG can leak from either saturated liquid or vapor location of tank.



Generates leak input boundary conditions for CFD modeling



Calculates time required for tank to empty



Fast and accurate modeling of leaking tanks and piping provides high quality CFD boundary conditions

Project Accomplishments and Progress: CNG Modeling

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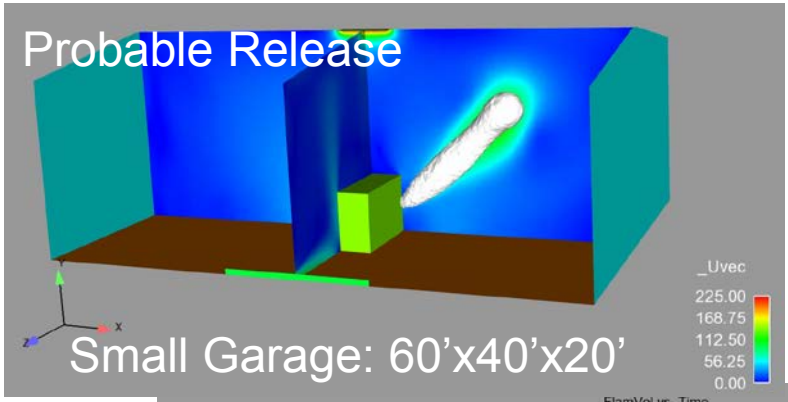
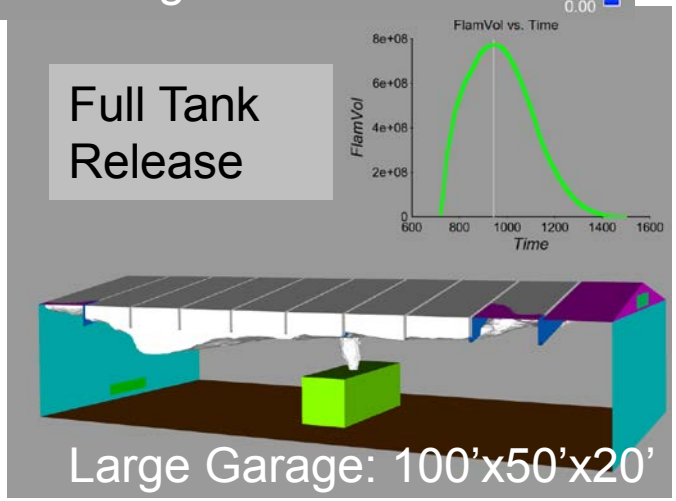
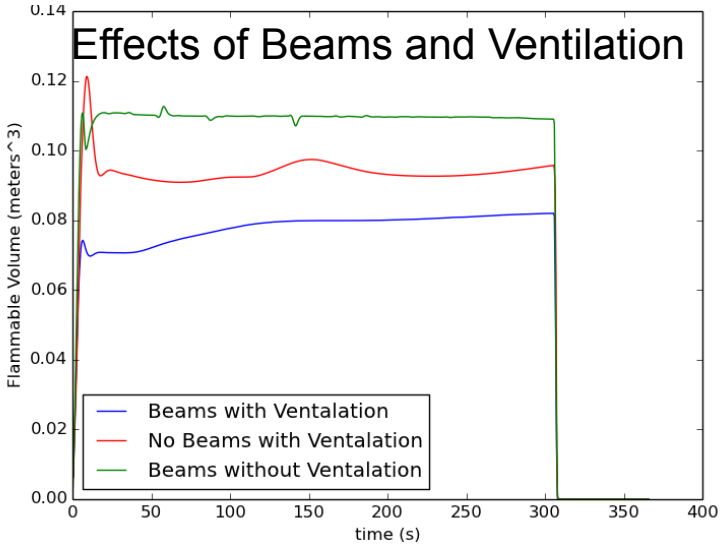
Computational Fluid Dynamics (CFD) is used to model leak scenarios in maintenance garages.

Scenarios were varied by:

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



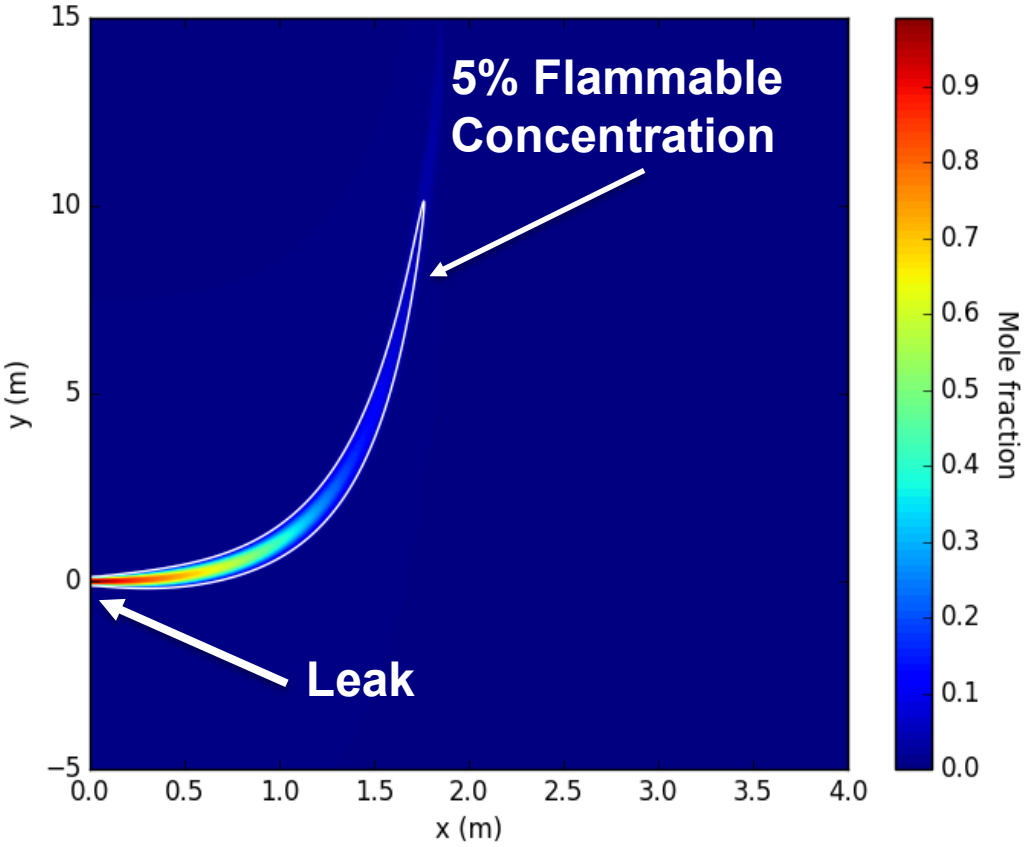




Results indicate that flammable concentrations can occur in regions not protected by NFPA 30A (lower than 18" from the ceiling).
Results can be used to assess sensor placement.

Project Accomplishments and Progress: Cold Plume Modeling

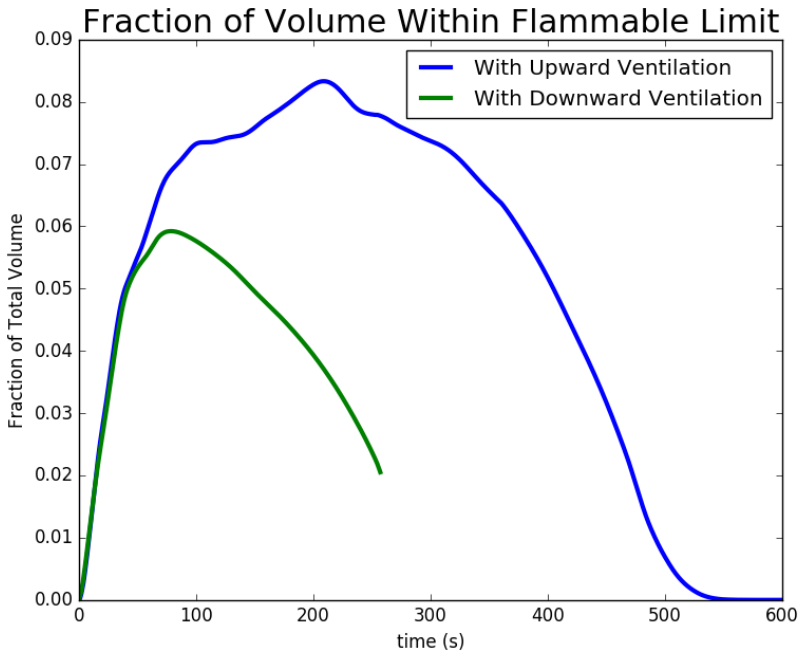
- Fast 2D modeling leak scenario release characteristics showing buoyancy effects and plume concentrations for initial estimate of flammable concentration locations
- Expanded on previously existing CNG plume model for LNG cryogenic releases. Leaks can be from either saturated liquid or vapor location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

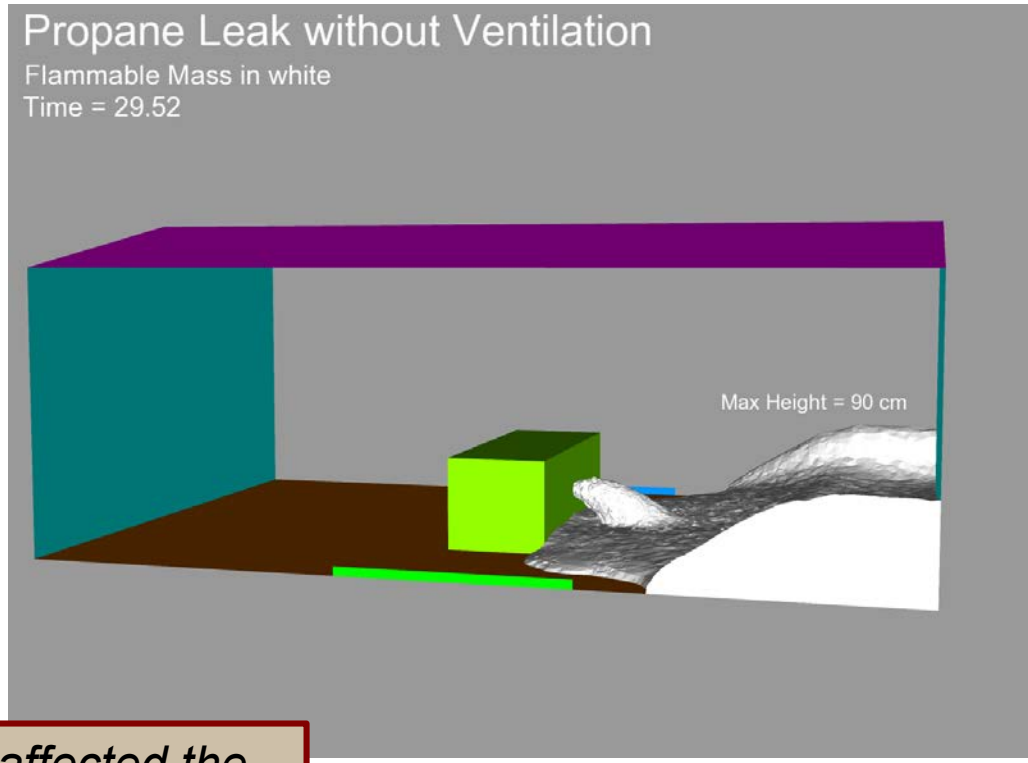


Fast modeling of CNG and LNG leak plumes provides 1st order estimate of leak shape

Propane Autogas Analysis

Preliminary work on leaks from propane tanks in a maintenance garage to show effects of ventilation.





Direction and amount of ventilation affected the amount of flammable concentrations of propane

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
- Presented at the Propane Autogas Technology Forum in Washington, D.C., Aug, 2016
- 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 VTO 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

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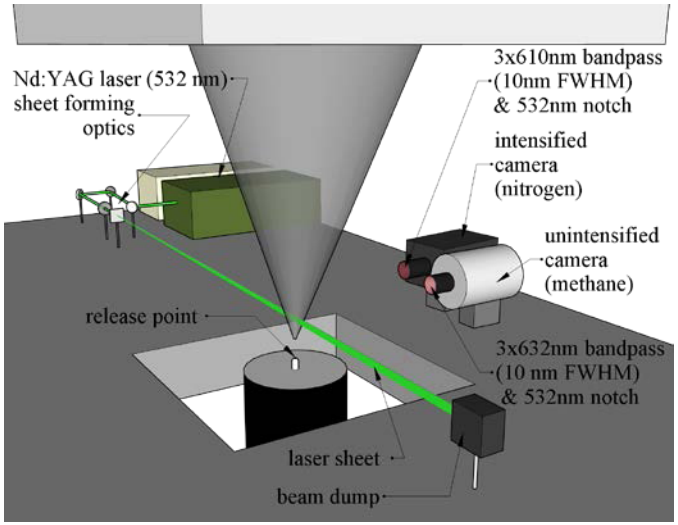
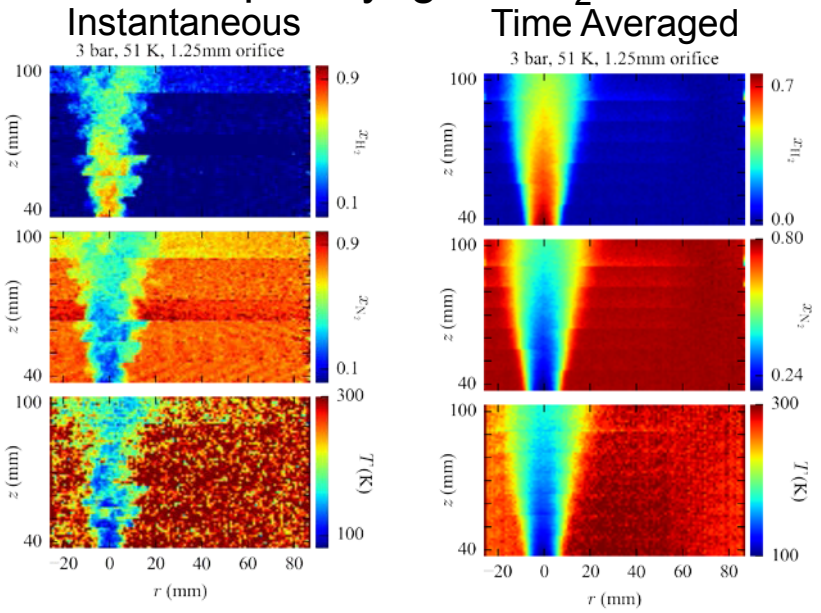
LNG experiments for understanding leak behaviors and model validation

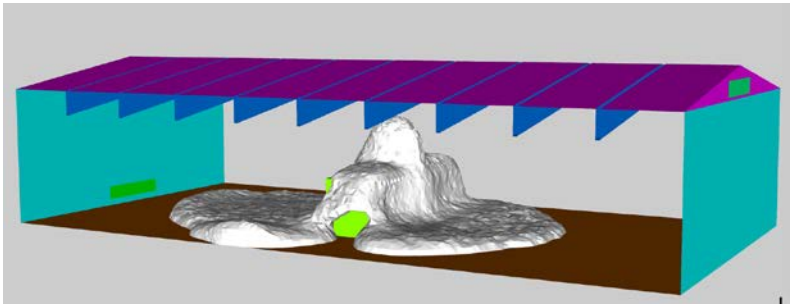
Experimental setup for liquid CH_4 (Planar laser Raman imaging)



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. We will quantify the differences between LNG and CNG leaks.



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

Additional Opportunities

- Leverage our expertise with H_2 vehicle infrastructure to other NGV areas beyond maintenance facilities
  - Risk-informed design of fueling stations
  - Understanding risks of NGVs driving in tunnels to inform appropriate safety restrictions
- Develop modeling for other alternative fuels such as propane to advance technical expertise with these fuels
- Creating a tool modeled off of HyRAM for use with natural gas (http://hyram.sandia.gov)
  - Easy user interface
  - Integrated Risk Assessment for system design

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.
  - Provided justification for a code change 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

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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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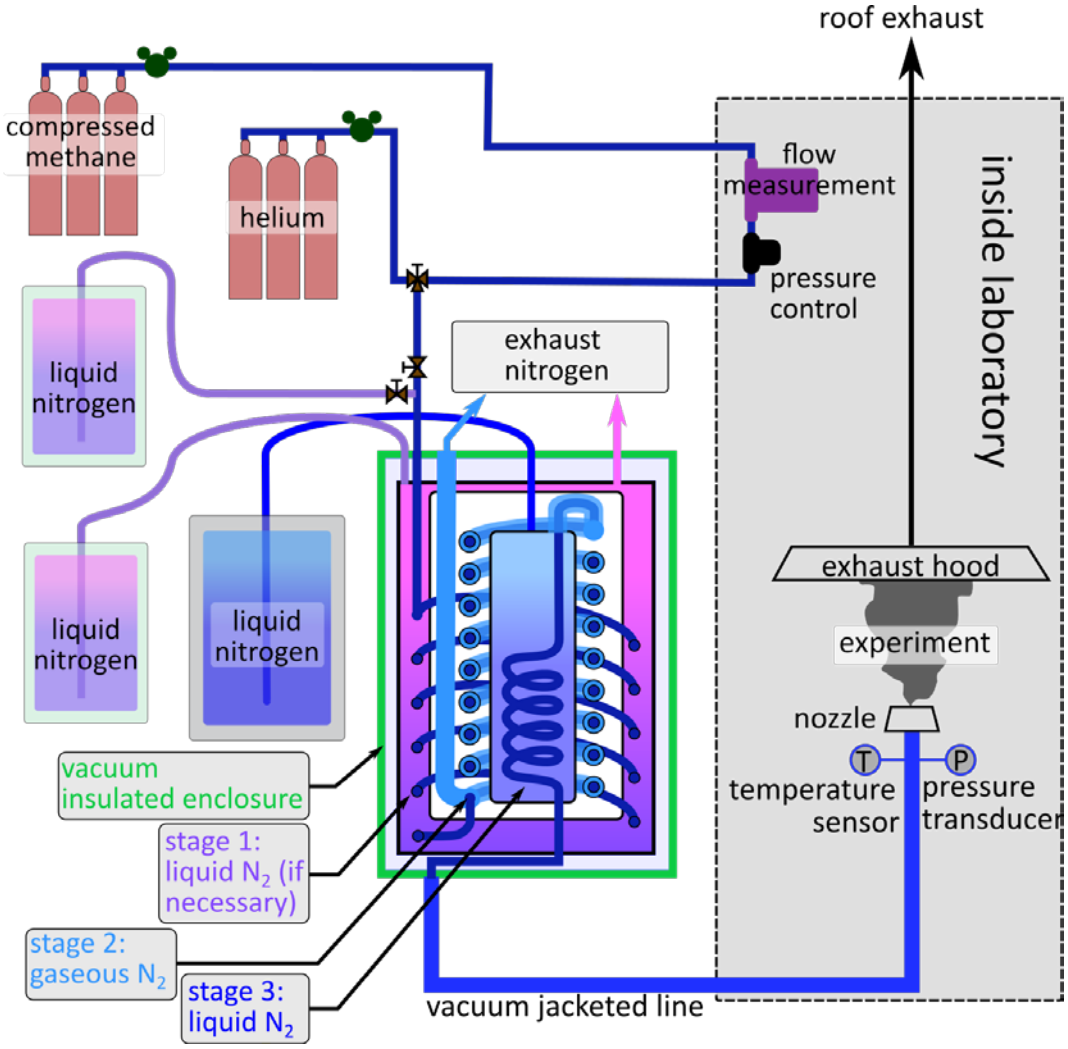
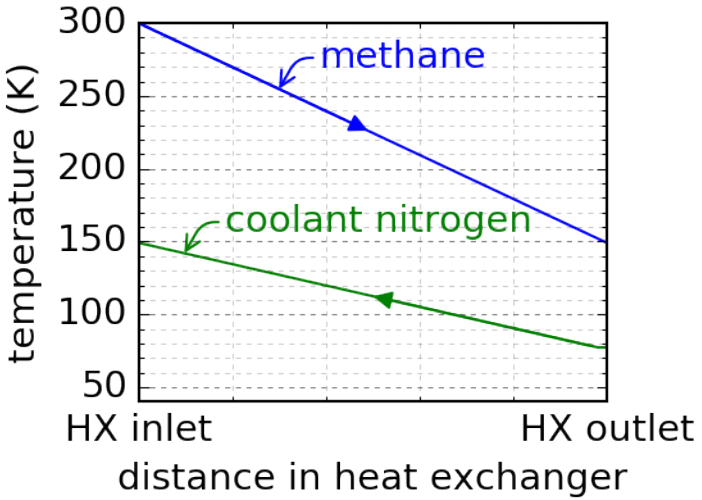
HAZOP Number	Component	Operation State	Hazard Scenario	Causes	Consequences	Consequence Class	Probability Class	Escalation
1	LNG-1 (Over pressure regulator)	3in, 4, 7, 8	External leakage from regulator body	Seal failure, mechanical defect, damage, etc.	Minor leakage of GNG	1	4	L
7	LNG-4 (LNG tank)	3in, 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