MULTI-COMPONENT FUEL VAPORIZATION AND FLASH BOILING

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DOE EERE Vehicle Technologies Office
Annual Merit Review Meeting

Project ID # ACS106

Project Overview

Timeline
- Start Date: January 2016
- End Date: December 2018
- Percent Complete: 35%

Barriers
- Inadequate data and predictive tools for fuel property effects on combustion and engine efficiency optimization.
- Inadequate data and predictive tools for fuel effects on emissions and emission control system impacts.

Budget

Total project funding
- DOE share: $685k
- Contractor share: $76k

Funding in FY 2016: $236k

Funding for FY 2017: $212k

Partner
- Argonne National Laboratory

Relevance and Objectives

Effective fuel atomization can optimize fuel efficiency while reducing emissions. Our goal is to expand current understanding of **multi-component (MC) fuel vaporization** and **flash-boiling** behaviors.

Objectives

- Design and develop a multi-component fuel vaporization model using both discrete and continuous thermodynamics methods.
- Develop a model for multi-component flash boiling. (*ANL*)
- Conduct corresponding experiments to verify the proposed models.
- Characterize flash boiling phenomena of multi-component fuel sprays by various optical and laser diagnostic techniques.

Diameter evolution

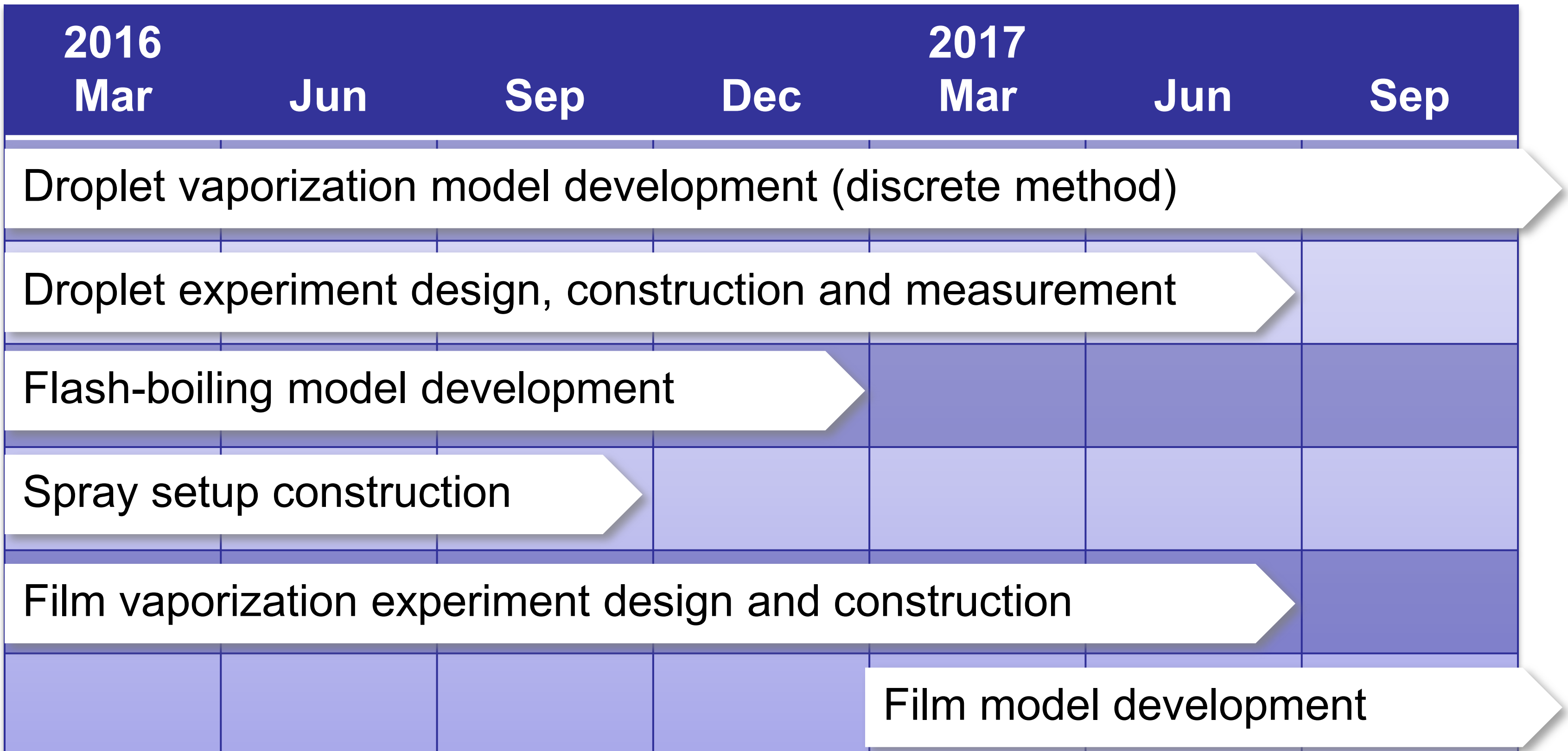
- Temperature histories
- Composition (concentration) histories

Thickness evolution

FY 2016/2017 Milestones

Date	Milestone	Status
Mar 2016	Base-model MC spray calculation	Complete
Jun 2016	MC flash-boiling model development	Complete
Sep 2016	Flash-boiling experimental design and setup	Complete
Dec 2016	MC droplet experimental design and setup	Complete
Mar 2017	Droplet radius and temperature measurement	In Process
Jun 2017	Film experimental design and setup	On track
Sep 2017	Spray droplet size and velocity measurement	On track

FY 2016/2017 Approach/Strategy

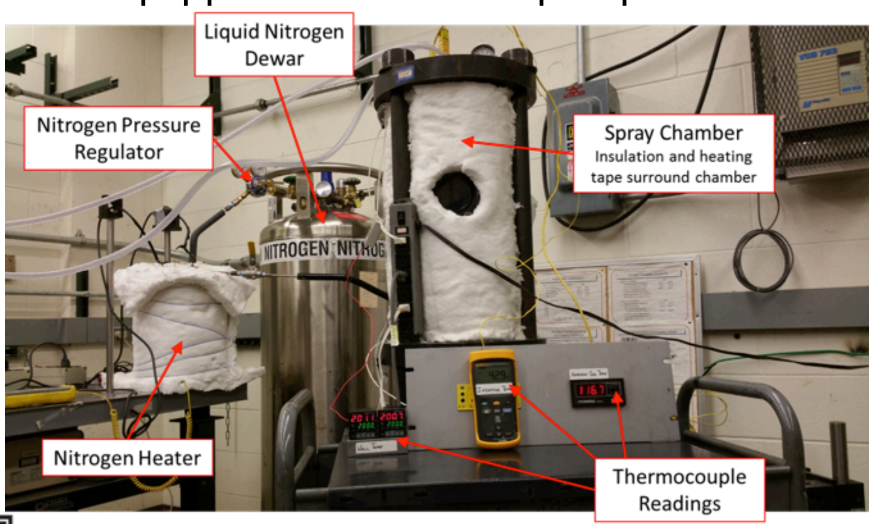


- Go/No-go Decision Point: Is the droplet chamber well sealed and heated? Can the chamber hold pressure up to 30 bars and temperature up to 500 K? Does the droplet generator produce the droplet consistently?

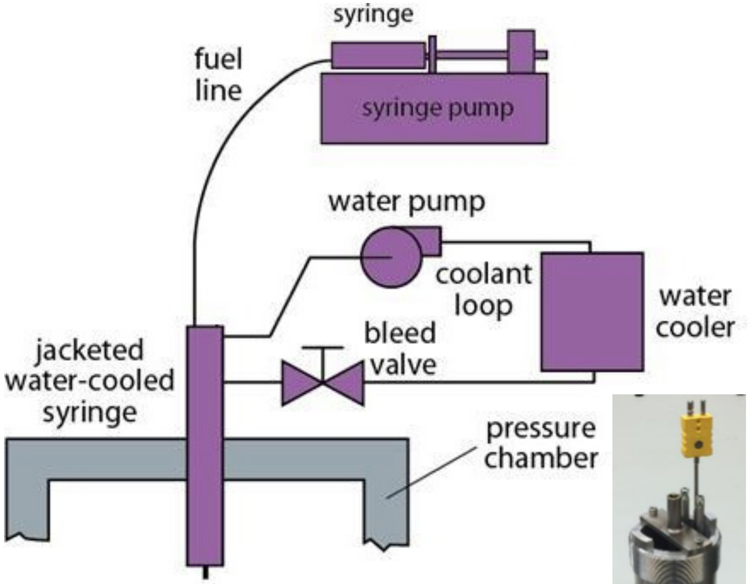
FY2016/2017 Technical Accomplishments

Droplet and Spray Experimental Setup

Chamber Specs
- Volume: 12.9 L
- 189 mm diameter x 462 mm height.
- Wall thickness: 33 mm
- 4 optical window mounts
- Flexible height.
- Equipped with vacuum pump



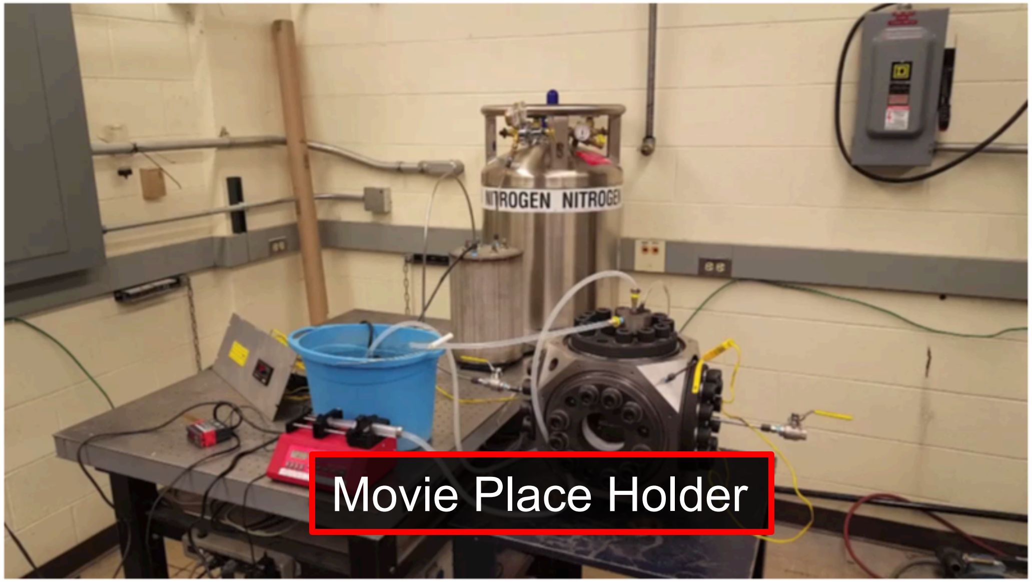
Droplet Injector Setup

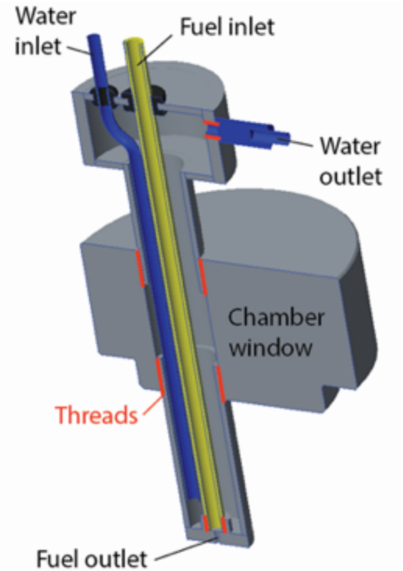


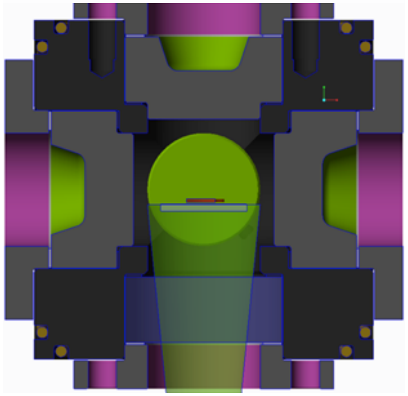
Spray Injector Setup
- Water cooled
- Includes a thermocouple for monitoring injection temperature.

Film Vaporization Setup

- Chamber internal volume: 1.8L
- 6 chamber window openings
- Dual tubular heaters
- Heated and pressurized to 600 K and 10 bar
- Film injection system
  - Undergraduate research opportunity project
  - Injection volume: 1 mL of the fuel





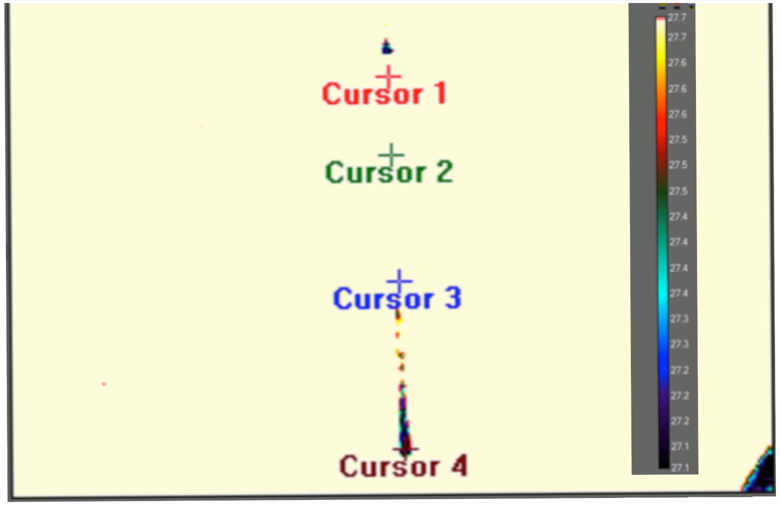


Chamber

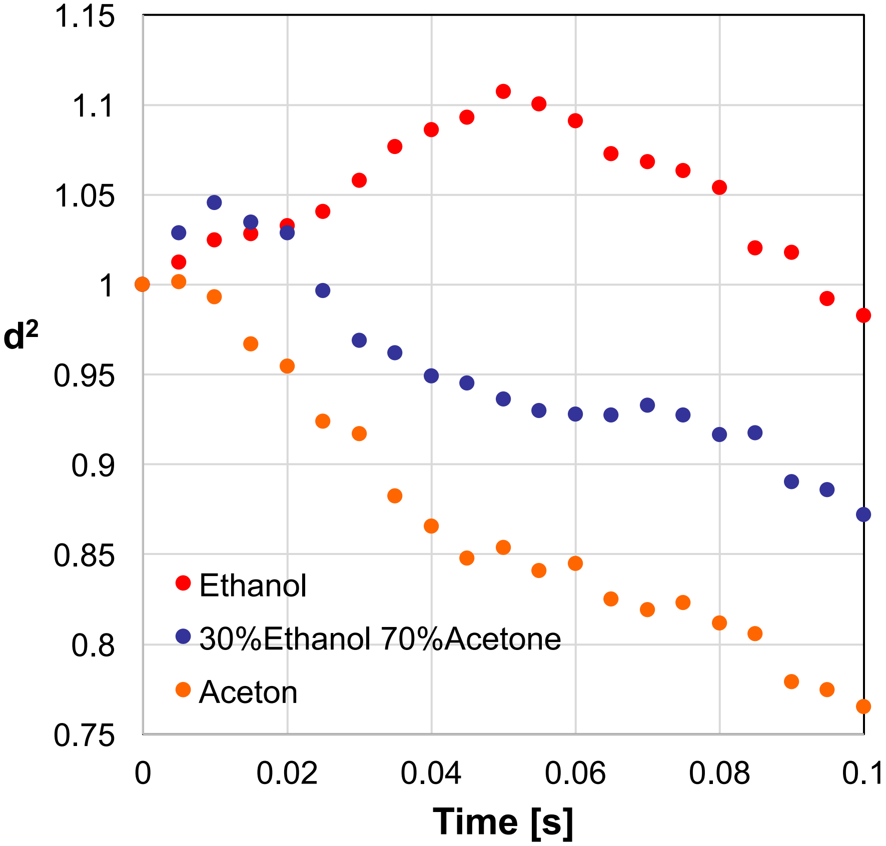
Droplet Temperature and Size Measurement

- Camera: Flir E 40
- Frame rate: 30 Hz (maximum)

Cursor	Temperature (° C)
1	27.2
2	27.2
3	27.2
4	27.1

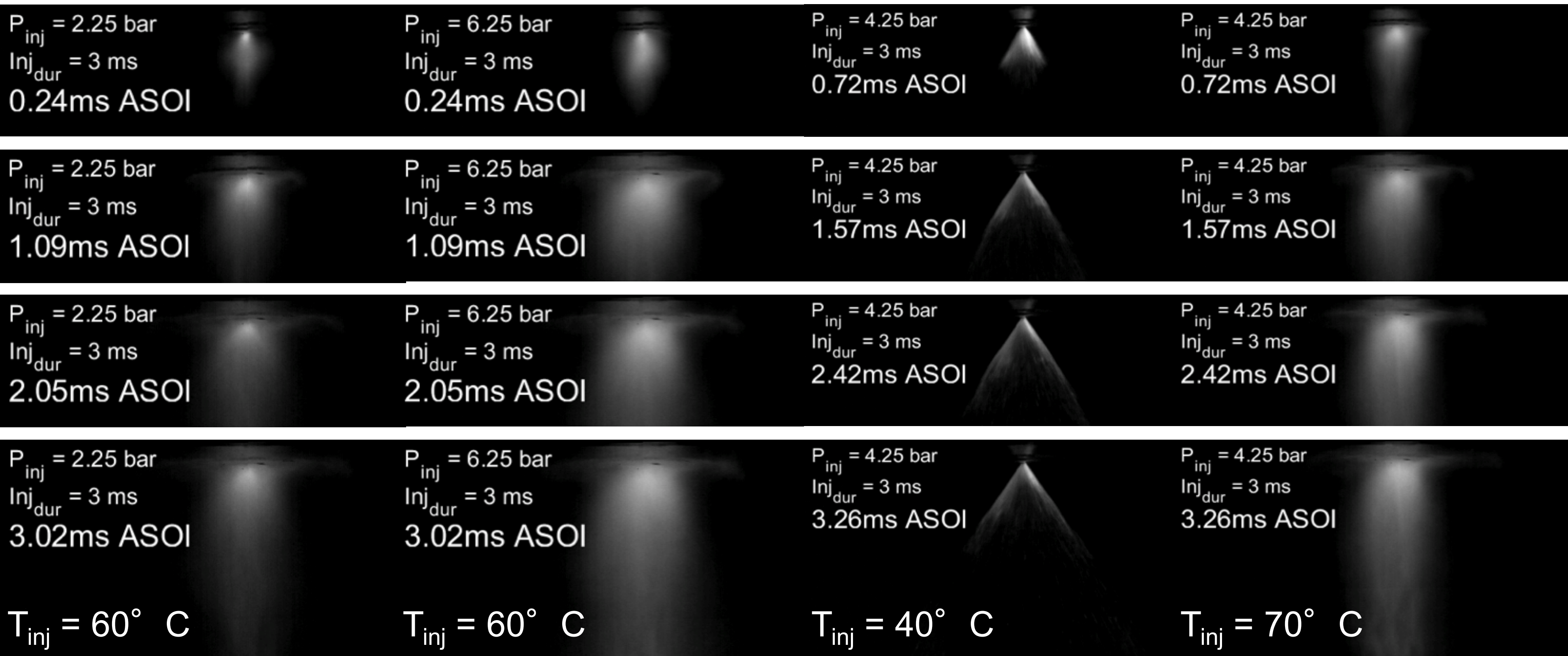


- Sample measurements show consistent droplet evaporation rate.



Spray Images

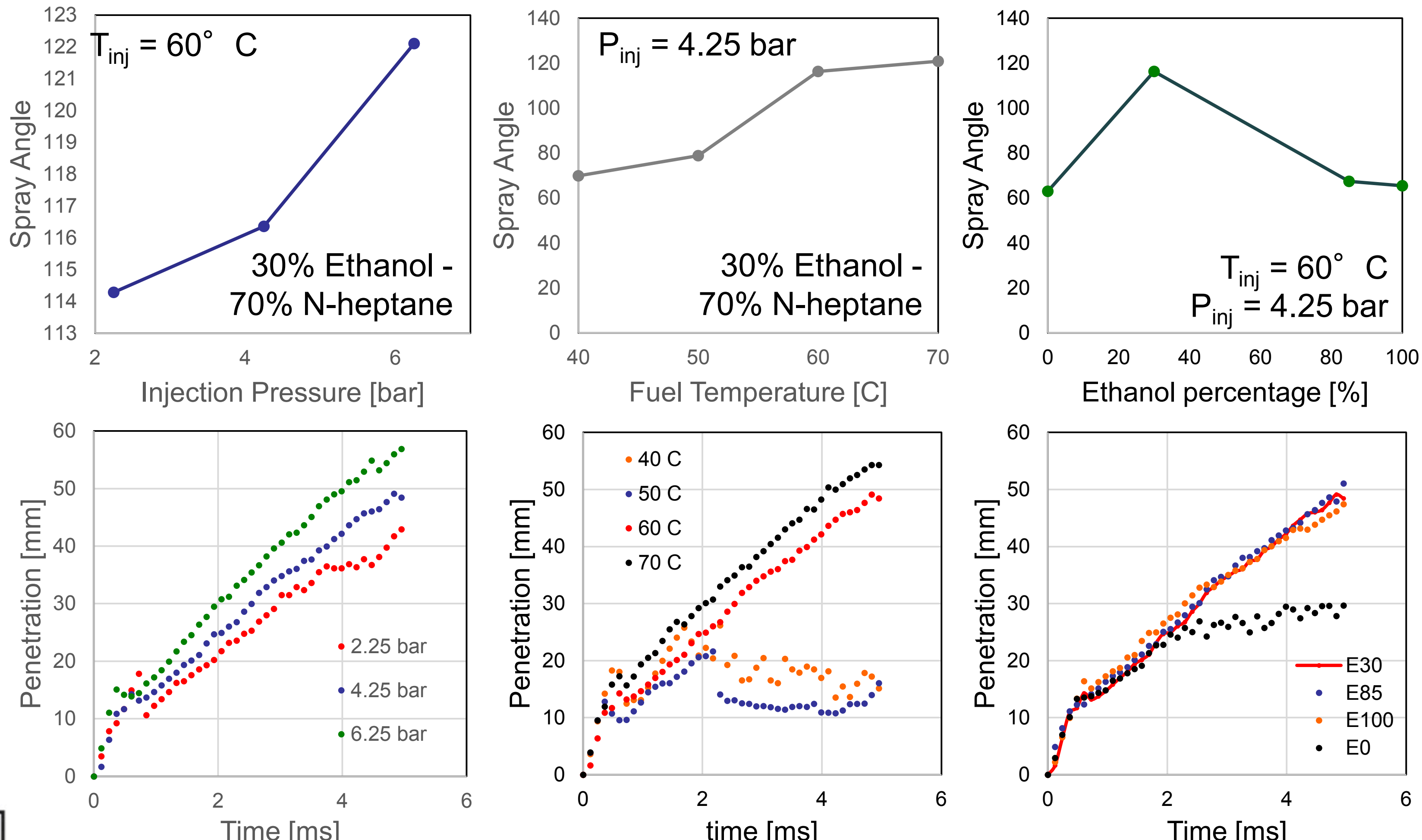
Images of hollow cone fuel spray were taken in the chamber with varying injection temperature and pressure conditions. Flash boiling phenomenon can be observed clearly in the liquid penetration images.



Fuel: 30% ethanol-70% n-heptane

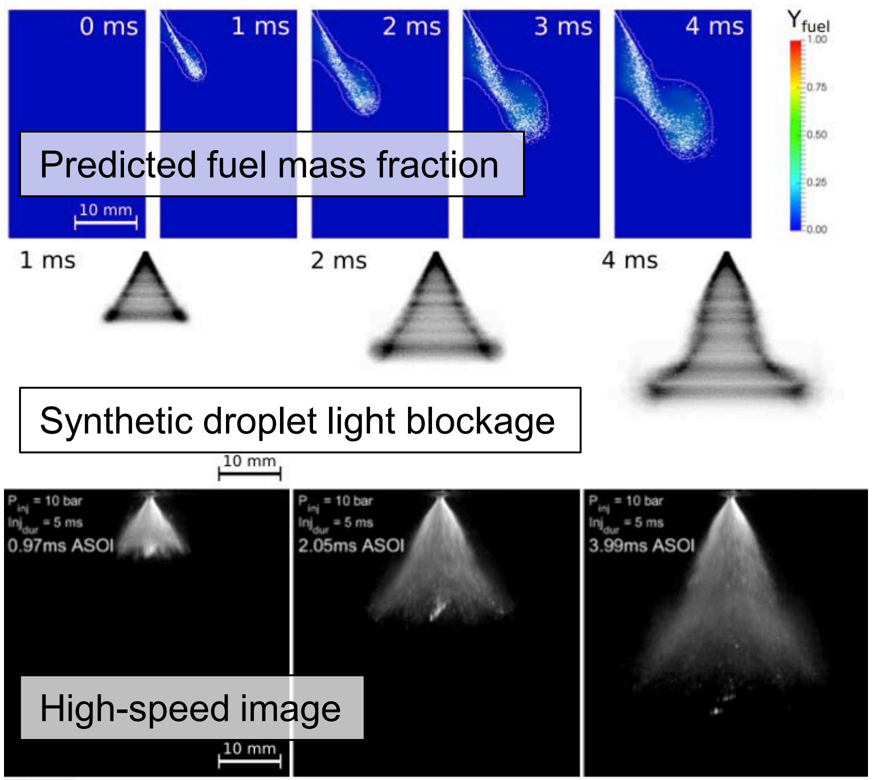
Spray Characterization

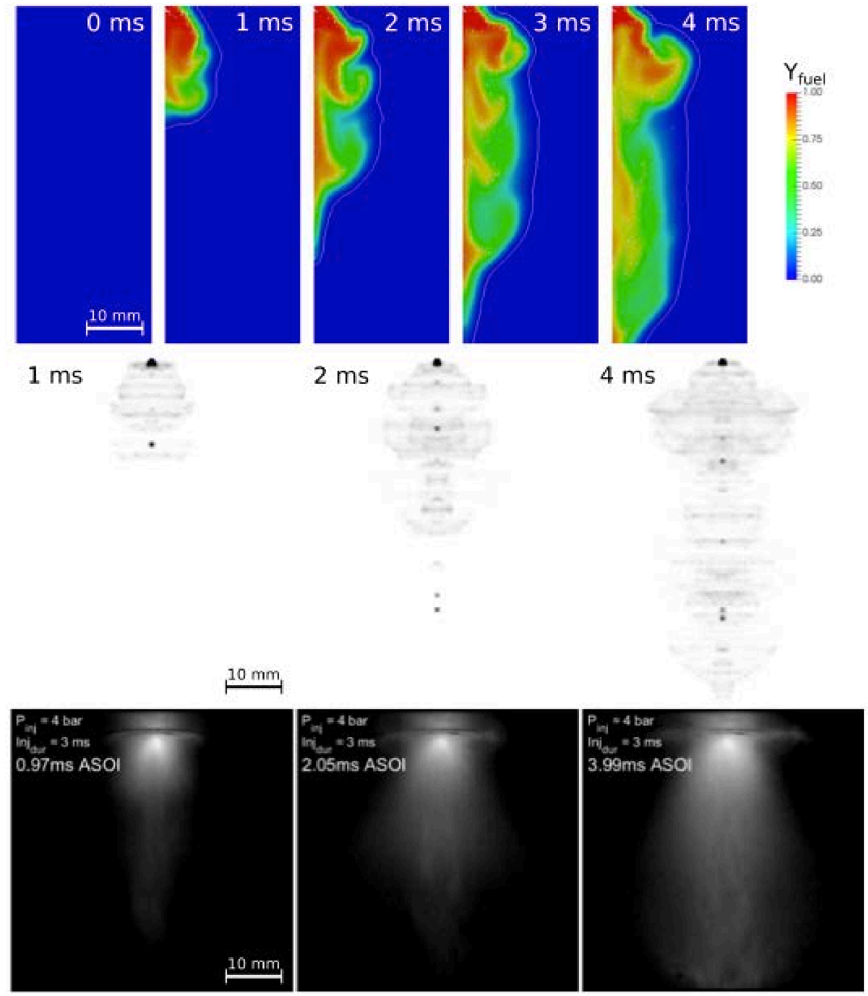
Spray liquid penetration response to flashing/non-flashing conditions and mixtures.



Hollow Cone Flash Boiling Model vs. Observation

The performance of a combined model for flashing and aerodynamic droplet breakup was constructed validated.





Major Features of the New Evaporation Model

Droplet liquid phase model

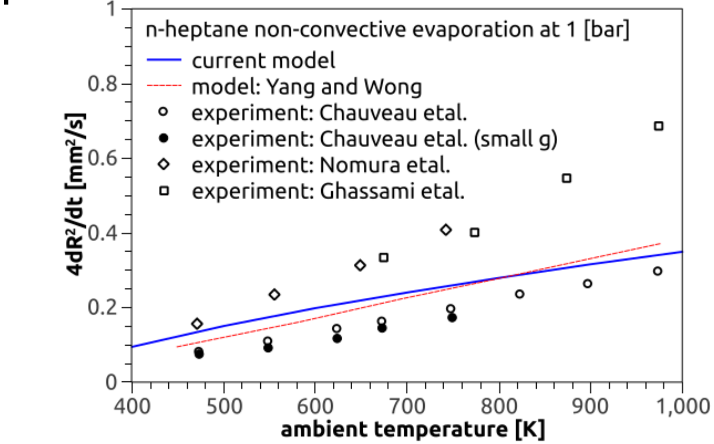
- 1-D FVM
  - Moving grid without cell deactivation
  - Degrade to 0-D (infinite diffusion model) when liquid is near-depletion
- Quasi 1-D model
  - Tracks the difference between surface state and mean state

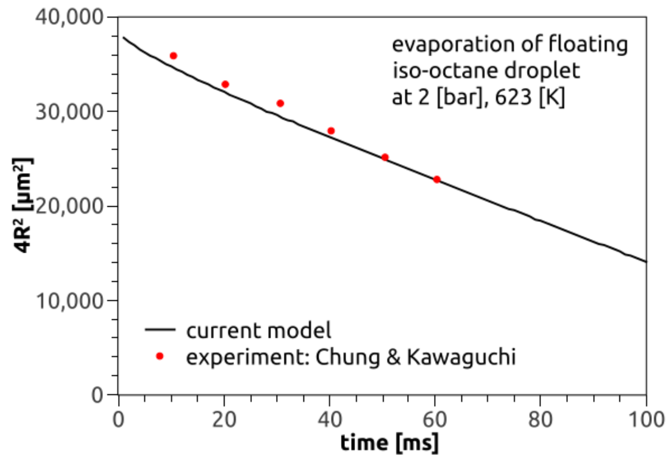
Fluid properties and VLE

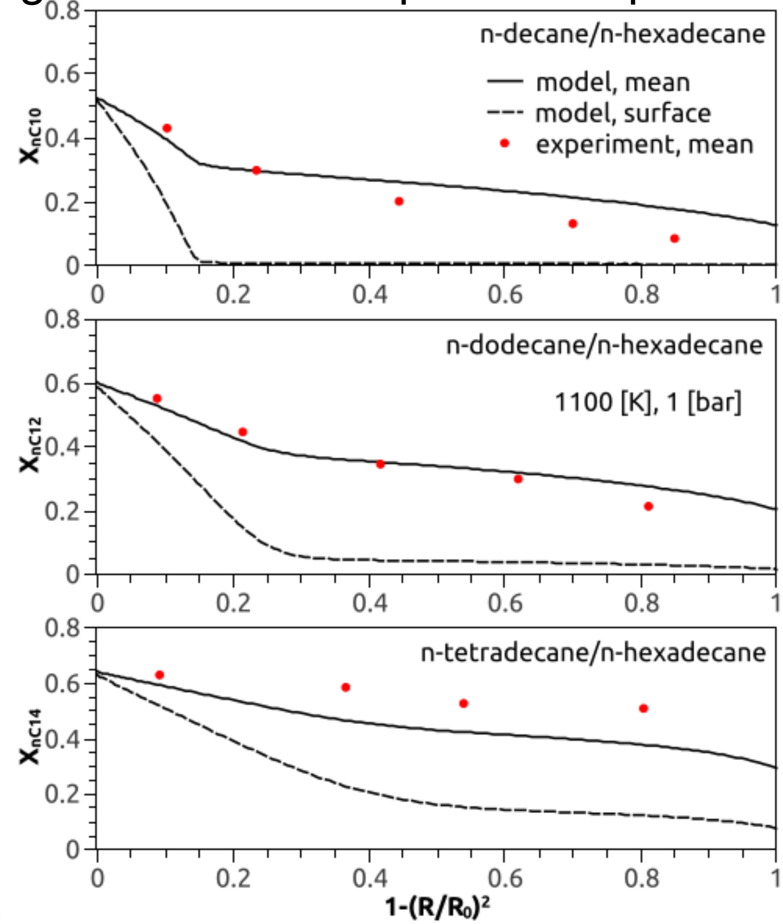
- Peng-Robinson EOS
- Proven thermal and transport property models for mixture
- Easy to find the input parameters
  - Only needs pure fluid parameters
  - All parameters can be easily found from either literature or public databases

Droplet Model Validation

Comparisons show reasonable agreement between the model and the experiments in ambient air for both single and multi-component droplets.





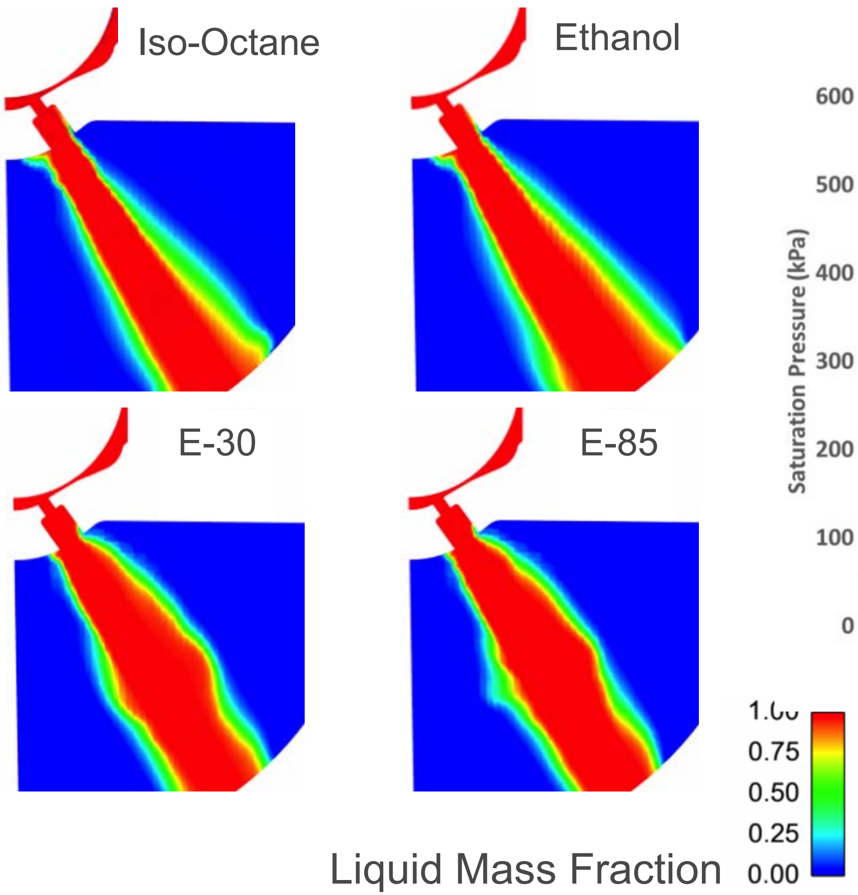


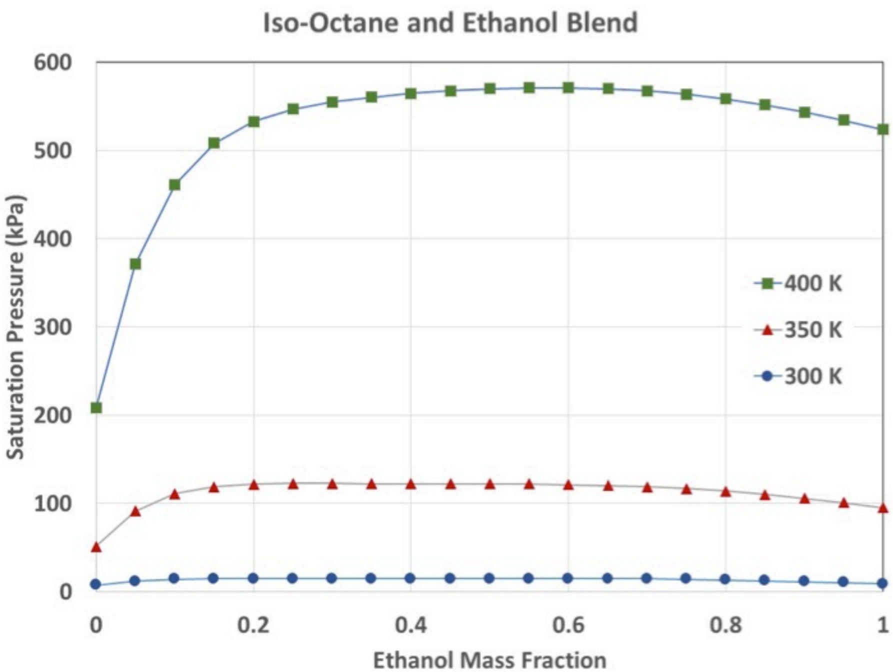
ANL Flash-boiling Model Development

- Run Eulerian simulation of internal and near-nozzle flow
- Capture phase change under flashing condition
- Create a map file at nozzle exit that provides necessary inputs for spray simulation
- Utilize the map file (one-way spray modeling)to run Lagrangian spray simulations
- Capture phase change due to convective heating and/or flashing in Lagrangian framework
- Spray simulation framework: CONVERGE v2.3
- Fuel injector: Spray G ECN
- Compare Rate-Of-Injection (ROI) and one-way approaches

Fuel Blend Effect

Increase in ethanol creates more flashing that causes jet protrusion.

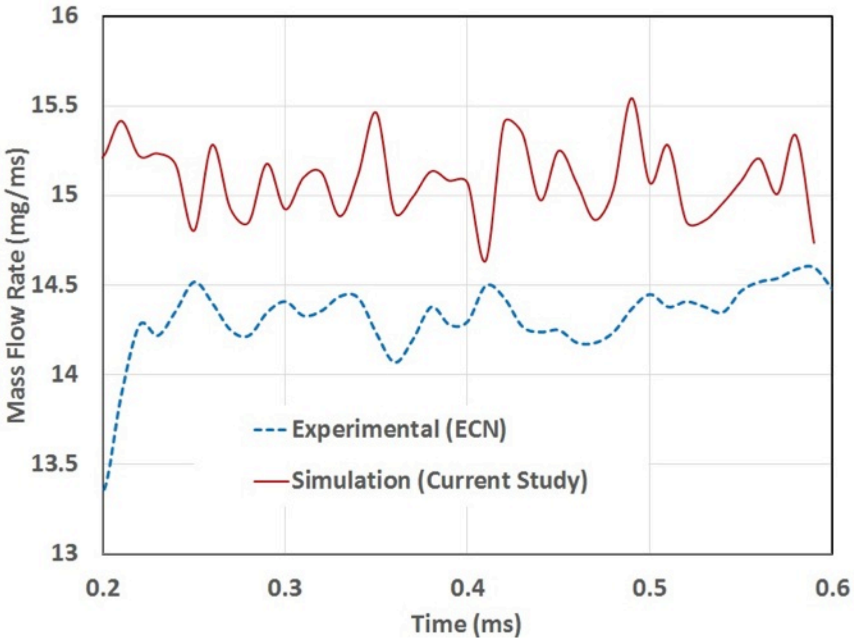


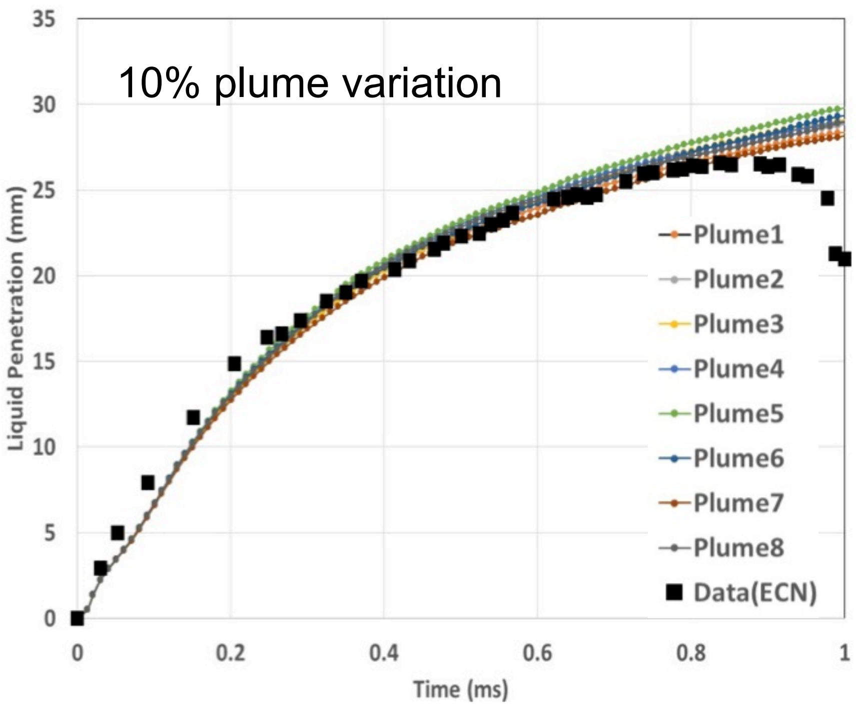


Blend can be more volatile than individual components. (Obtained using REFPROP v9.1)

Non-flashing Case Validation

- Spray G submerged case study (chamber filled with iso-octane) is done using 3.9 million cells with minimum grid size of 17.5 µm in the orifices.
- Under Spray G condition (chamber filled with N_2 at 573 K), liquid penetration study showed the potential of one-way method for capturing plume-to-plume variation.





Responses to Previous Year Reviewers' Comments

- This project is a new start.

Partnership/Collaboration

Argonne NATIONAL LABORATORY

- Develop multi-component flash-boiling model and integrate into current high-fidelity VOF framework.

Remaining Challenges and Barriers

- Secure proper lasers to perform laser diagnostics for fuel characterization.
- Obtain high temporal resolution image for optical temperature measurement of multi-component fuel droplet.

Proposed Future Work

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

- Ongoing:
  - Experimental measurement of fuel droplet composition (GC/MS, LIEF)
  - Flash boiling model
    - Develop a more robust phase change model for cavitation and flashing
    - Compare ROI and 1-way predictions for other conditions
    - In-depth analysis of moving needle transients
    - Further development in blended fuel flashing simulations
  - Droplet and film model development/validation using the discrete method

- [Q3 Milestone] Design and implement of film vaporization system
  - Setup high-speed imaging and other optics system

- [Q4 Milestone] Experimental measurements of flash boiling spray
  - Droplet sizing (PDA, PDS), composition evolution (LIEF), and temperature evolution (2-color LIF)

Summary

- Experimental setup for multi-component fuel vaporization for the following studies were completed:
  - Droplet
  - Spray
- Film experiment setup is on track to complete during FY2017
- Fuel droplet radius and temperature measurements have been obtained; composition measurement is ongoing
- Flash-boiling model development showed homogeneous relaxation model is reasonable for GDI applications. Good agreement with data was observed for ROI and 1-way simulations, where 1-way has the ability to capture plume-to-plume variations
- Droplet model performed well against historical data for multi-component fuel blend

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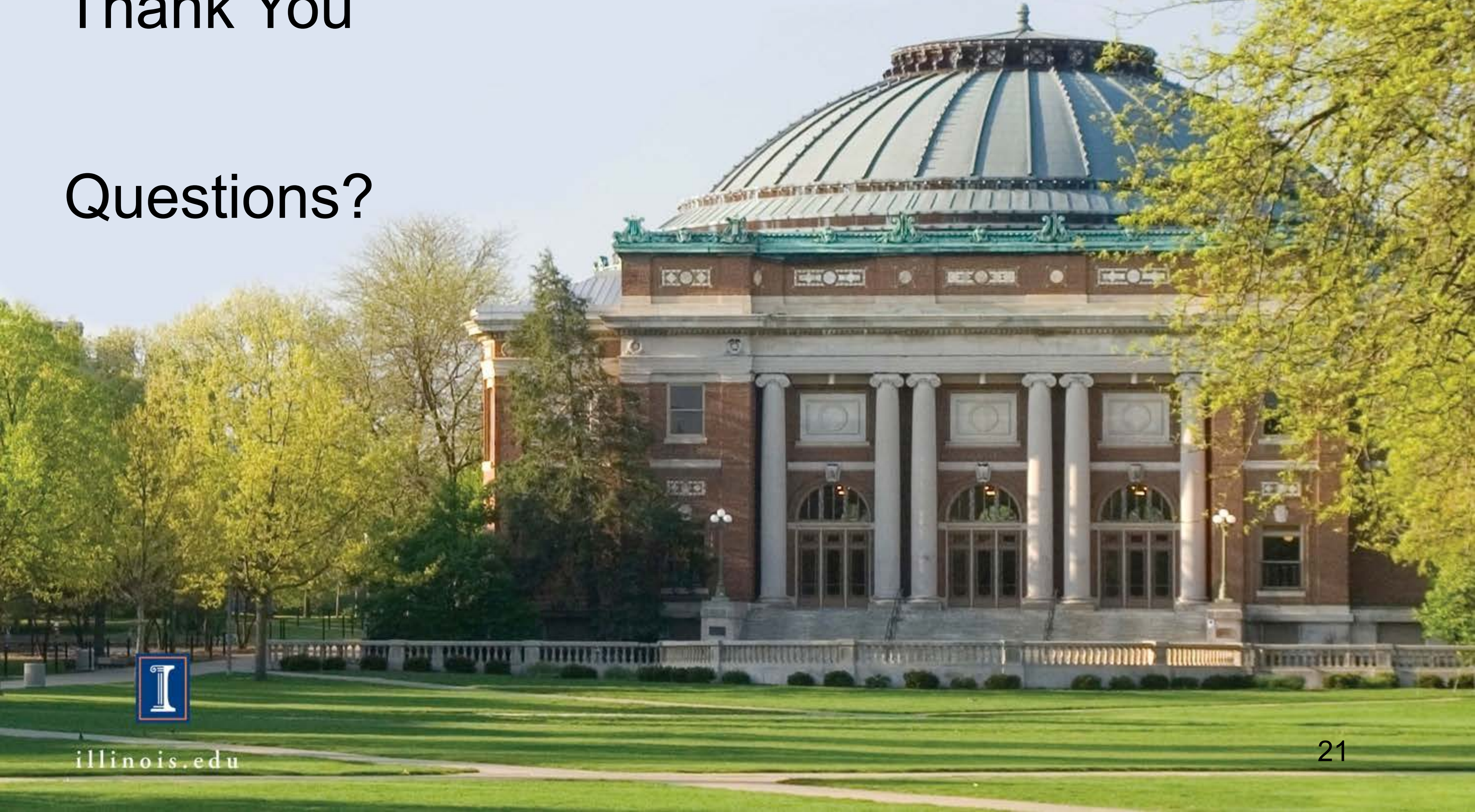
Thank You

Questions?



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BACKUP SLIDES

Droplet Sub-model Validations

The viscosity and thermal conductivity sub-model have been validated, and the same goes for the vapor-liquid equilibrium solver in the model.