



# Comparison of Lean Blowout for National Jet Fuels Combustion Program (NJFCP) Fuels in a Lean-Front-End Combustor

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# Lean Blowout (LBO) in a Lean-Front-End Combustor:

## Key Questions

1. How sensitive is LBO to fuel composition for a lean-front-end combustor?
2. What fuel characteristics are most important?
3. Can CFD predict the LBO fuel sensitivity *trends* in a lean-front-end combustor?



# Experiment



## Facility

- 5-bar flametube
- 3-in circular cross-section
- 3 windows
- Instrumentation
  - Air temperature, pressure
  - Fuel and air flow rates
  - Pressure dynamics
  - High speed cameras



## Test Hardware: LDI

- 7-point lean direct injection (LDI)
- Each of the 7 fuel-air mixers consists of a 60° swirler followed by a converging-diverging venturi.
- A FN=0.7 fuel injector is inserted through the center of each swirler



## 4 NJFCP Reference Fuels

- **A-2:** "Average" Jet-A, Derived Cetane Number (DCN) 49
- **C-1:** Gevo isoparaffinic kerosene (IPK), DCN 16
- **C-4:** Mixture of Gevo and Sasol IPK, DCN 28
- **n-dodecane**, DCN 73.5



## Test Conditions

- Combustor inlet temperature: 450 F (500 K)
- Combustor pressure: 70 psia (4.8 bar)
- Fuel flow kept constant
- Air flow increases from 0.3 lbm/sec (0.14 kg/sec) to LBO



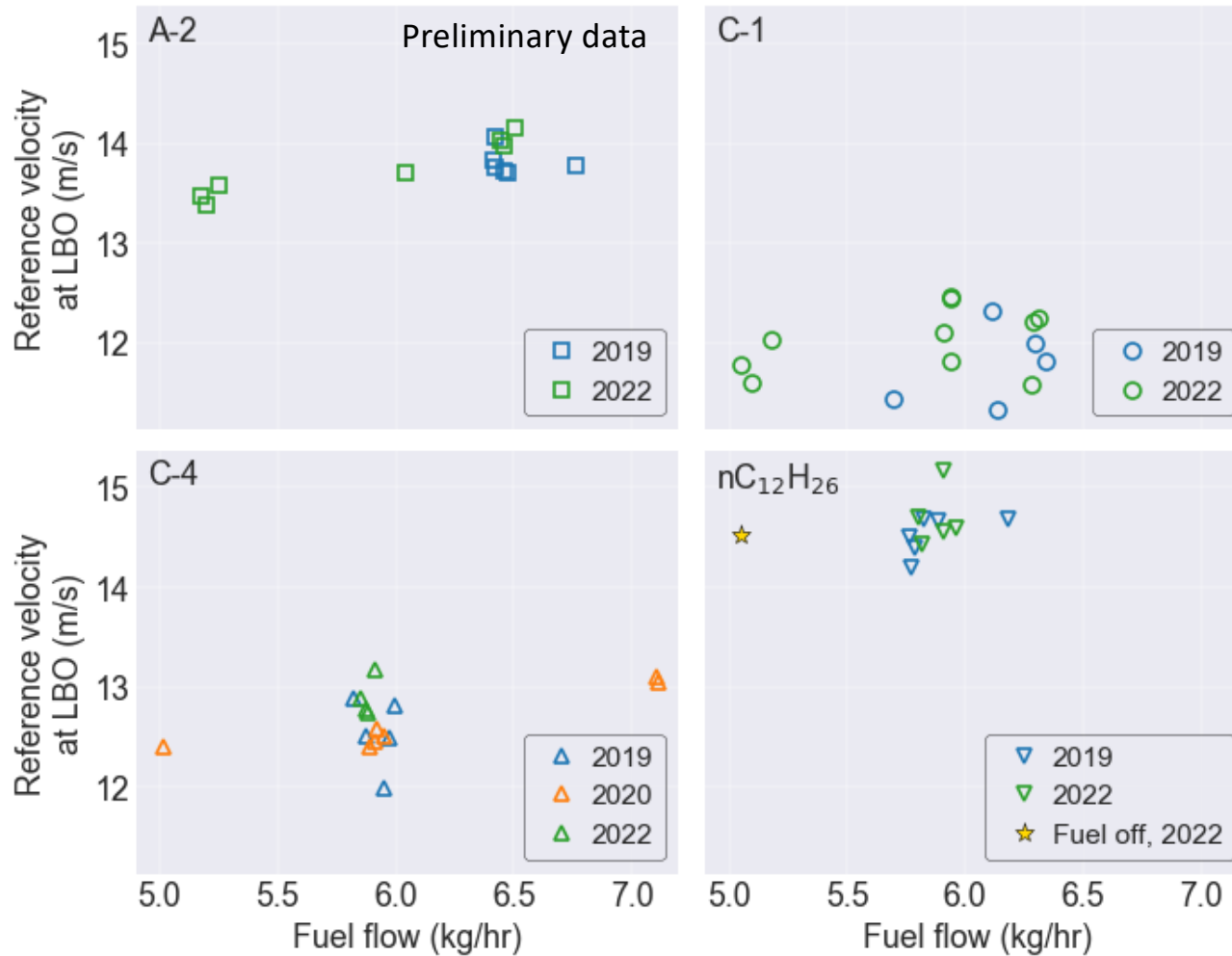
## Approach to LBO

- Increase air while keeping fuel flow rate constant
- Only the pilot (center) element is fueled
- Multiple LBOs/fuel. For each LBO, the fuel flow rate was kept constant but the fuel flow was at times set to different values.

With 4 NJFCP fuels, approach LBO at pilot-only, low power conditions by INCREASING AIR.

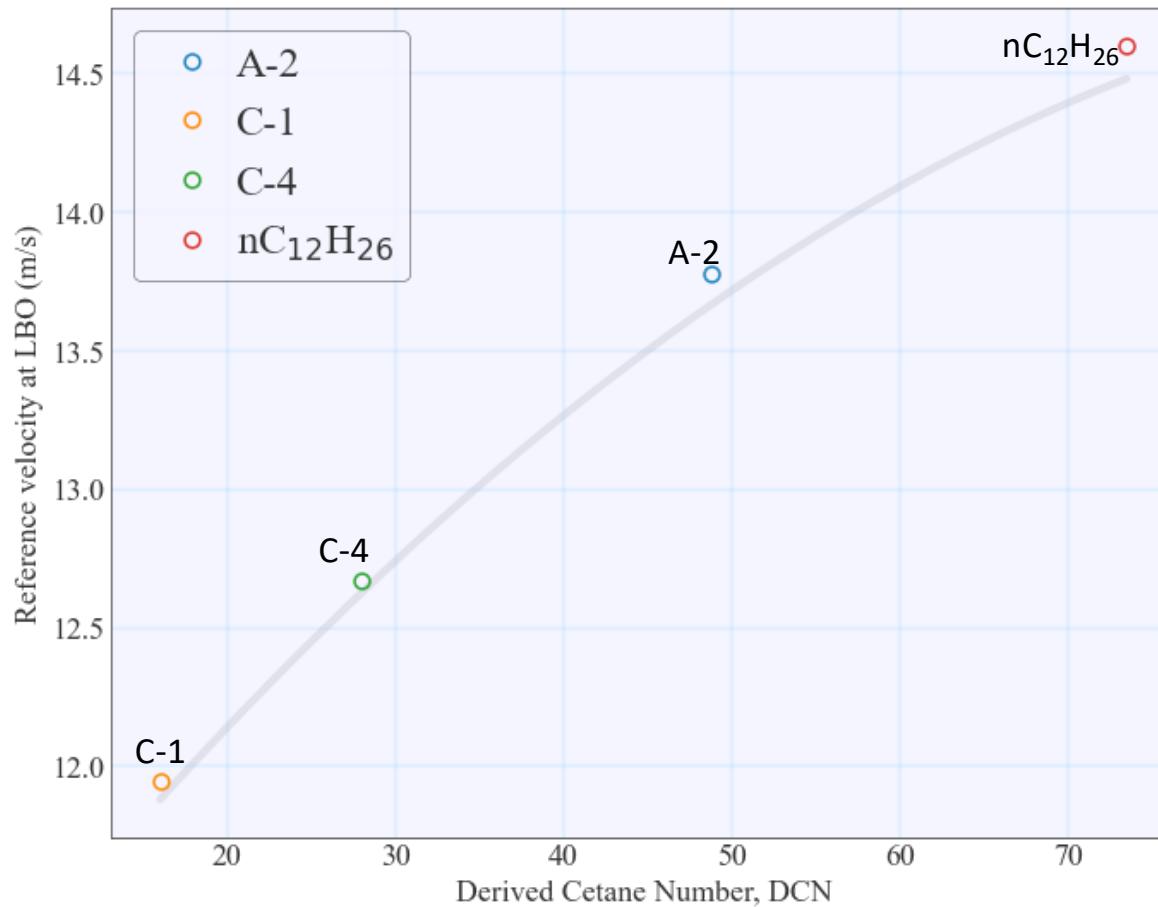


# Fuel Flow Rate Effects on LBO



Air flow rate at LBO does not depend strongly on fuel flow rate → reference velocity is a more meaningful parameter than equivalence ratio.

# Fuel Flow Rate Effects on LBO

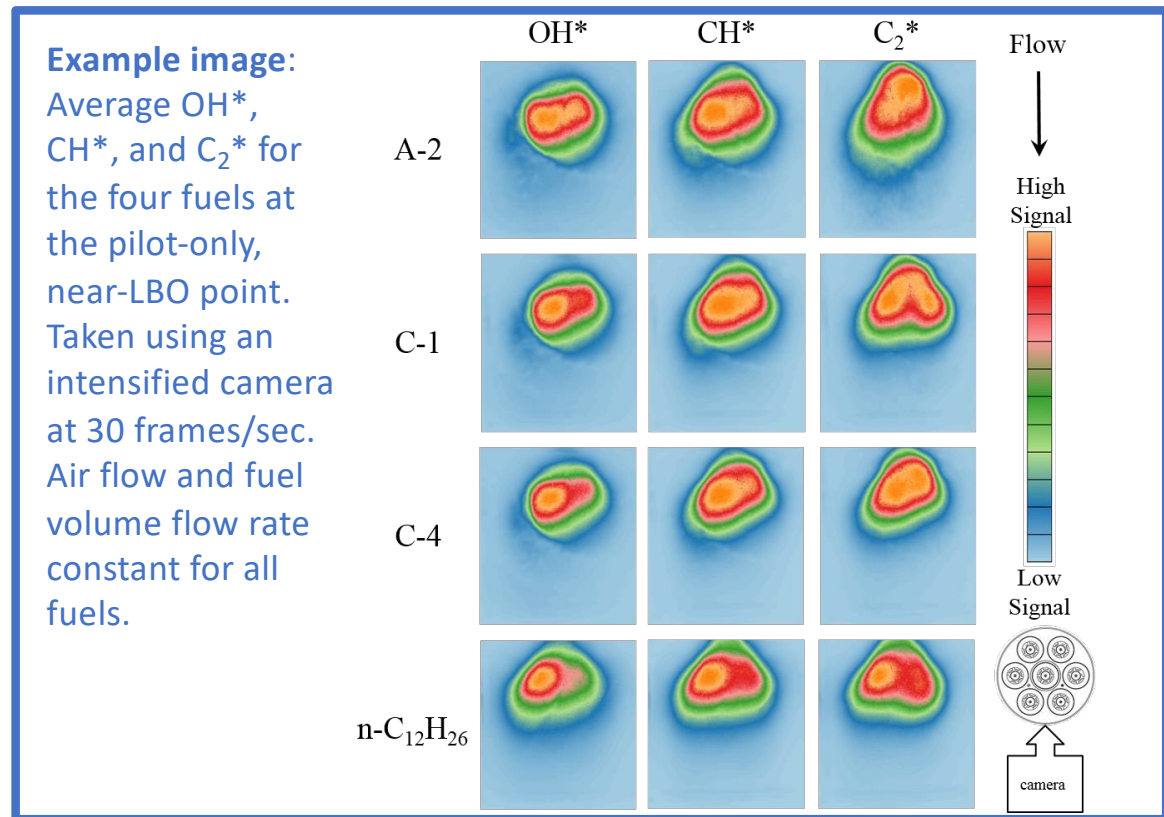


Reference velocity at LBO is a smooth function of derived cetane number.

# Optical Diagnostics



- Standard or High-Speed Color Camera
- Standard and high-speed intensified grayscale cameras for flame and chemiluminescent speciation
- Additional diagnostics at a steady near-LBO condition.
  - Additional diagnostics obtained for other non-LBO tests points with different combustor inlet conditions and all 7 elements fueled.

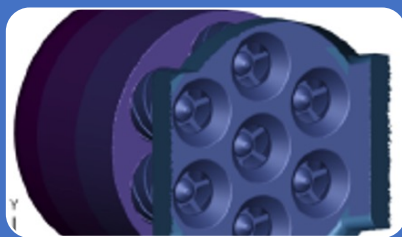


# Lean Blowout CFD Simulations: Predict LBO fuel sensitivity in a lean-burn combustor design.



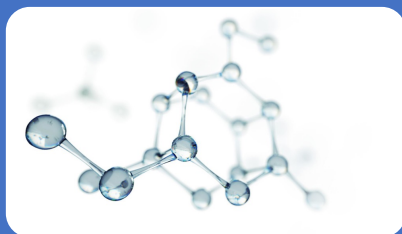
## Experimental data: 2019 7-Point LDI results

- Fuels: A-2 average jet and C-1 Gevo
- One fuel flow rate per fuel



## CFD codes

- **OpenNCC**: In-house unstructured mesh combustion CFD code
- **Converge**: Commercial combustion code, includes adaptive mesh refinement

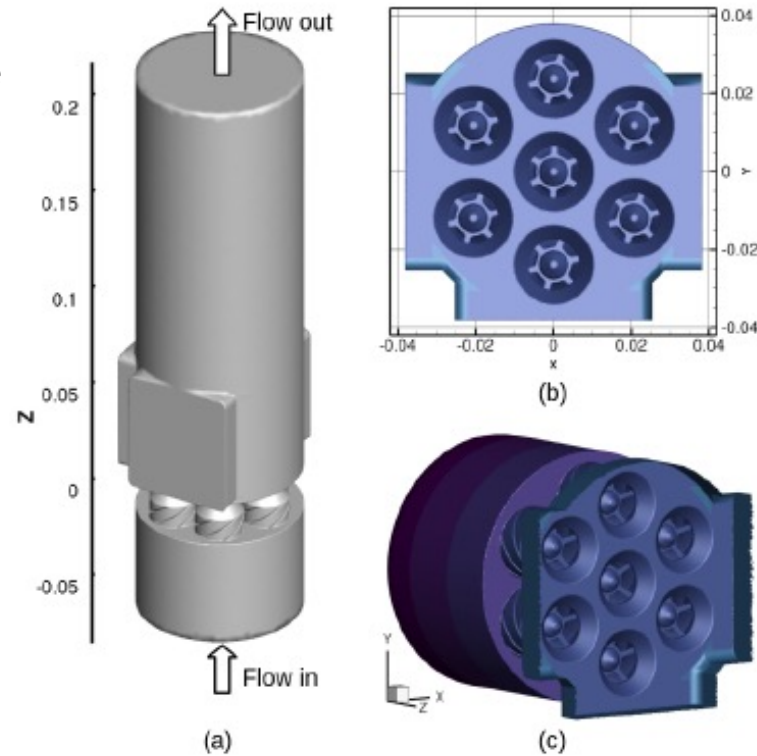


## Chemistry: HyChem mechanisms, <https://web.stanford.edu/group/haiwanglab/HyChem/>

- **Skeletal**: based on directed relation graph and sensitivity analysis reduction; 41 species for A2 (**Converge only**)
- **Reduced**: mechanism includes a second stage reduction using a quasi-stead-state approximation; 31 species for A2 (**Converge and OpenNCC**)

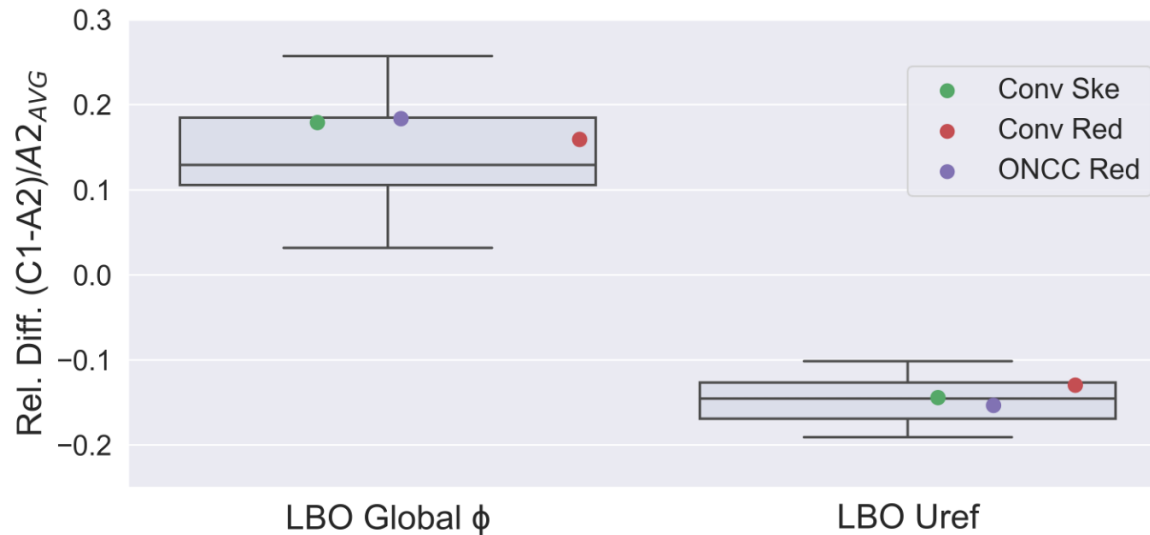
# CFD Domain

- CFD boundary conditions are set to match the typical experiment conditions
- All surfaces are adiabatic.
- Only the center injector is fueled.
- Fuel mass flow rates are fixed and the air mass flow rates are increased in step-wise manner until LBO occurs.





# Comparison of CFD Results with Experiments



- The range of the experimental results is shown by the box plots, the CFD by the points
- Both OpenNCC and CONVERGE simulations predict LBO within experimental range of fuel relative difference in:
  - Equivalence ratio ( $\phi$ ) for a fixed fuel flow rate :  $(\phi_{C1} - \phi_{A2}) / \phi_{A2}$ .
  - Reference velocity (Uref) :  $(Uref_{C1} - Uref_{A2}) / Uref_{A2}$

# Lean Blowout (LBO) in a Lean-Front-End Combustor:

## Summary

1. For these *increasing air* experiments, the key fuel properties appears to be Derived cetane number (DCN).
2. The reference velocity at LBO increases smoothly with DCN. The reference velocity for the fuel with the highest DCN (n-dodecane) is more than 20% higher than that for the fuel with the lowest DCN (C-1).
3. Two CFD codes (OpenNCC and Converge) successfully predicted the LBO fuel sensitivity *trends*.