Combustion of Ammonia and Ammonia-Hydrogen Mixtures for Gas Turbines

19th Annual Ammonia Energy Conference

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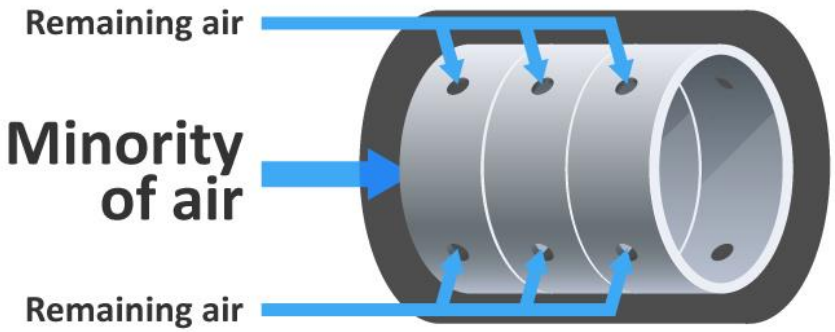
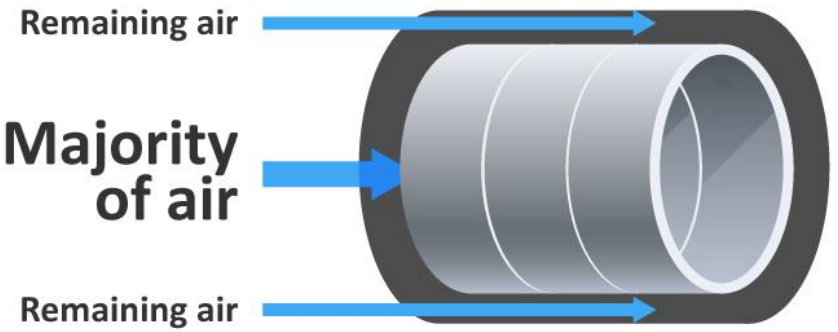
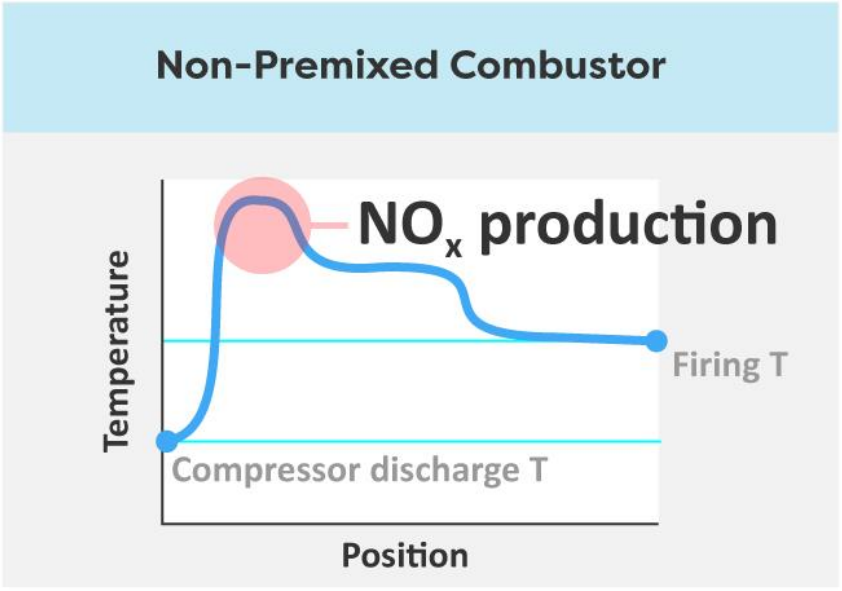
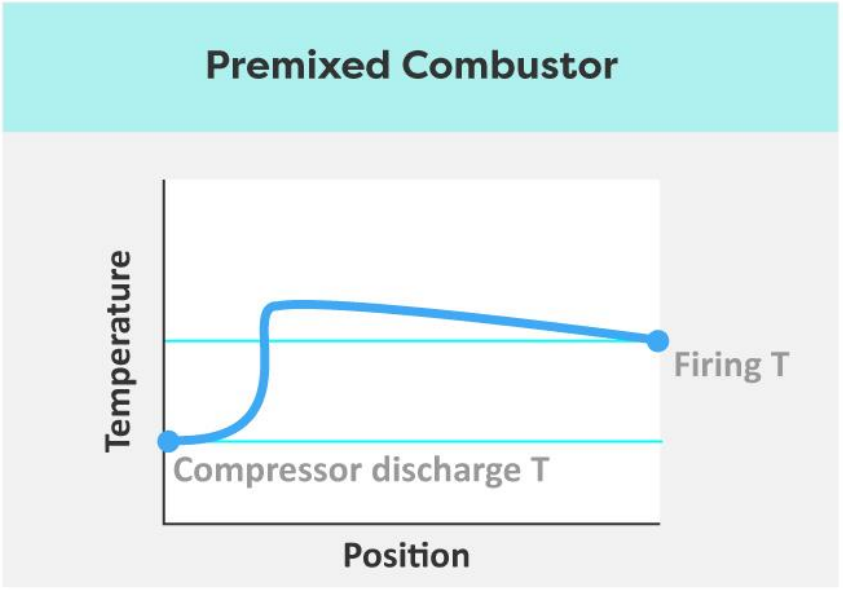
The General Difference in Diffusion vs DLN Technology





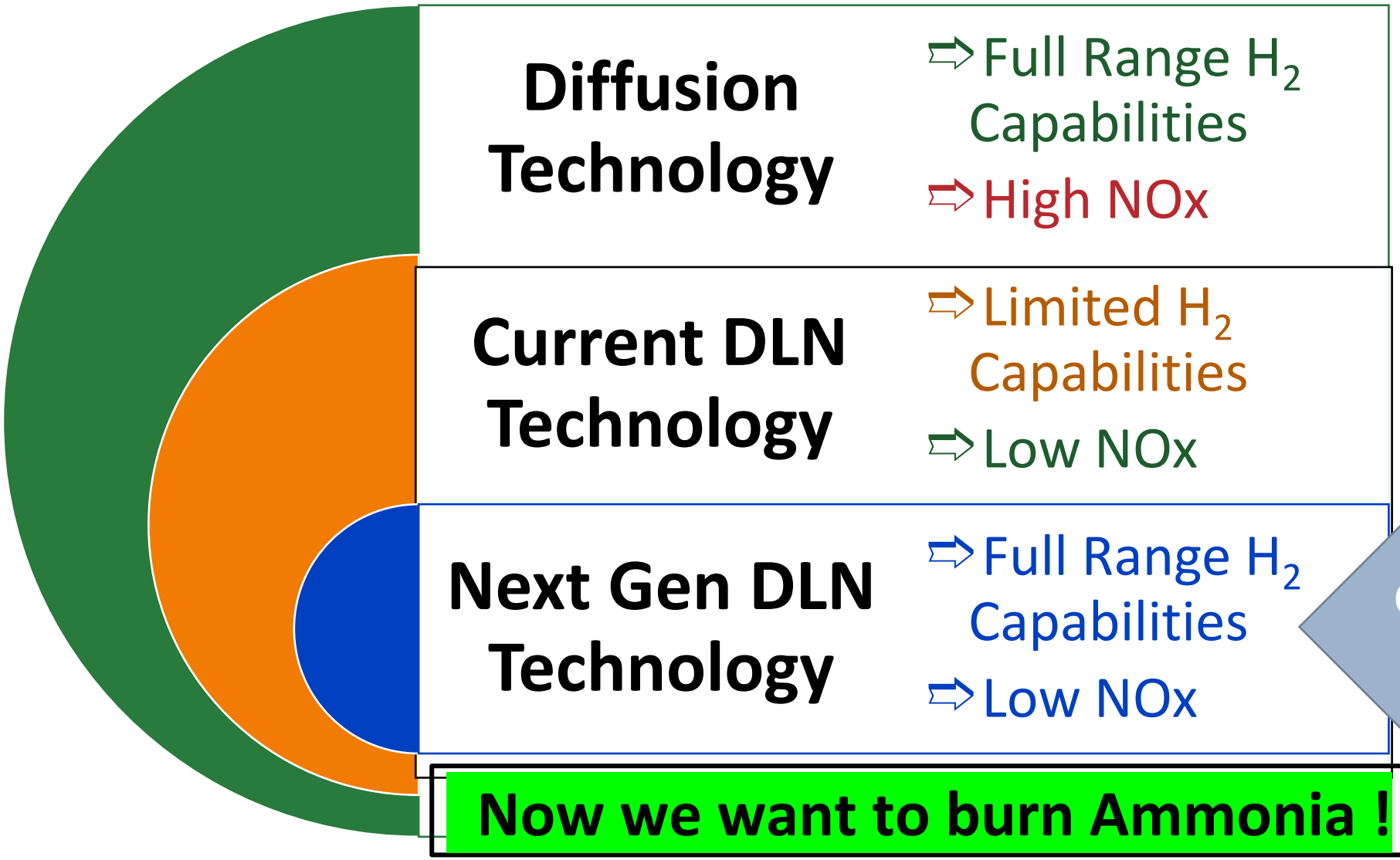




Diffusion

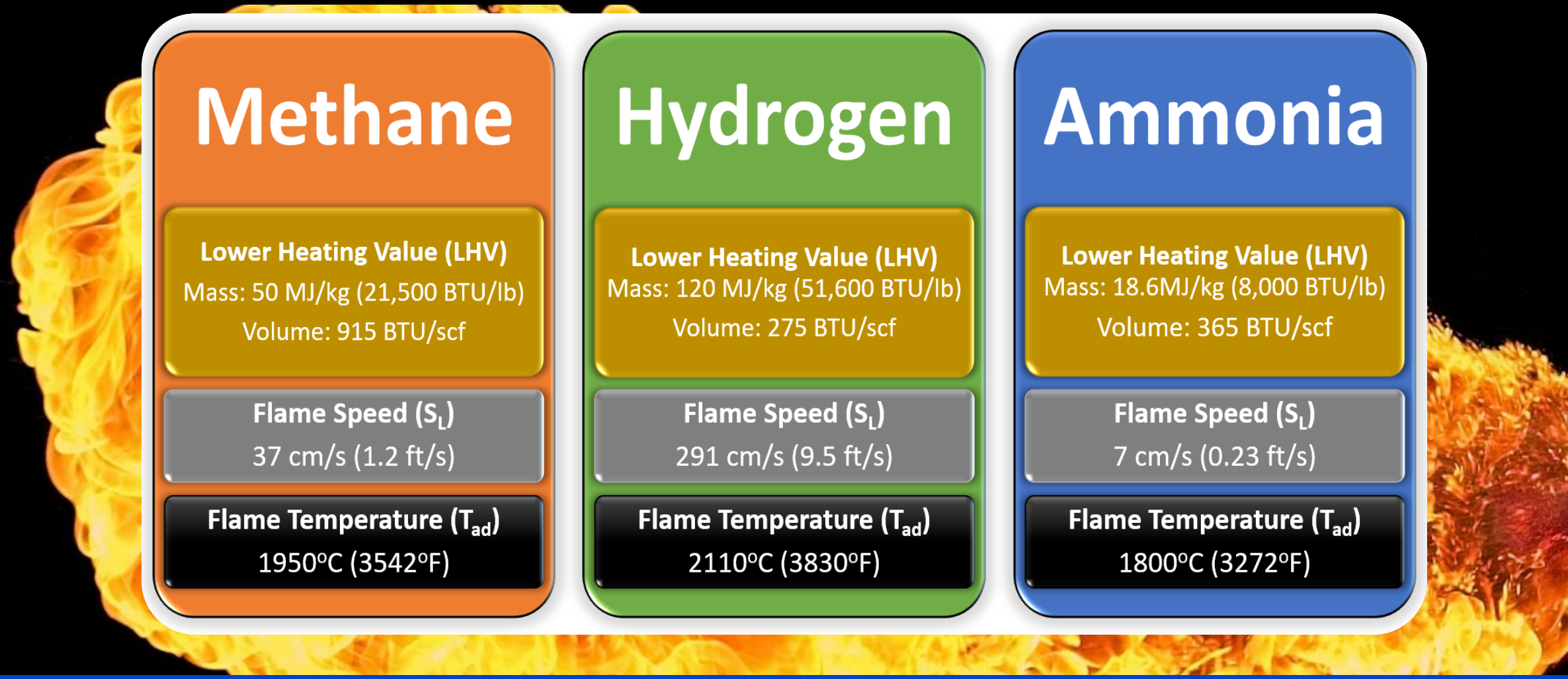
Dry, Low NOx

Gas Turbine Hydrogen Challenges



Current Development Focus & Need

How do the Various Fuels Compare?



Methane	Hydrogen	Ammonia
Lower Heating Value (LHV) Mass: 50 MJ/kg (21,500 BTU/lb) Volume: 915 BTU/scf	**Lower Heating Value (LHV)** Mass: 120 MJ/kg (51,600 BTU/lb) Volume: 275 BTU/scf	**Lower Heating Value (LHV)** Mass: 18.6MJ/kg (8,000 BTU/lb) Volume: 365 BTU/scf
Flame Speed (S_L) 37 cm/s (1.2 ft/s)	**Flame Speed (S_L)** 291 cm/s (9.5 ft/s)	**Flame Speed (S_L)** 7 cm/s (0.23 ft/s)
Flame Temperature (T_{ad}) 1950°C (3542°F)	**Flame Temperature (T_{ad})** 2110°C (3830°F)	**Flame Temperature (T_{ad})** 1800°C (3272°F)

Hydrogen burns 9 times faster than Methane &
42 times faster than Ammonia

DOE Funded Project: Investigation of Ammonia for Combustion Turbines (IACT)

- Goal
  - In-depth evaluation of ammonia as a zero-carbon fuel for power generation
    - Achieved through an iterative physics-, computational- and experimental approach resulting in a pilot combustor design validated through tests

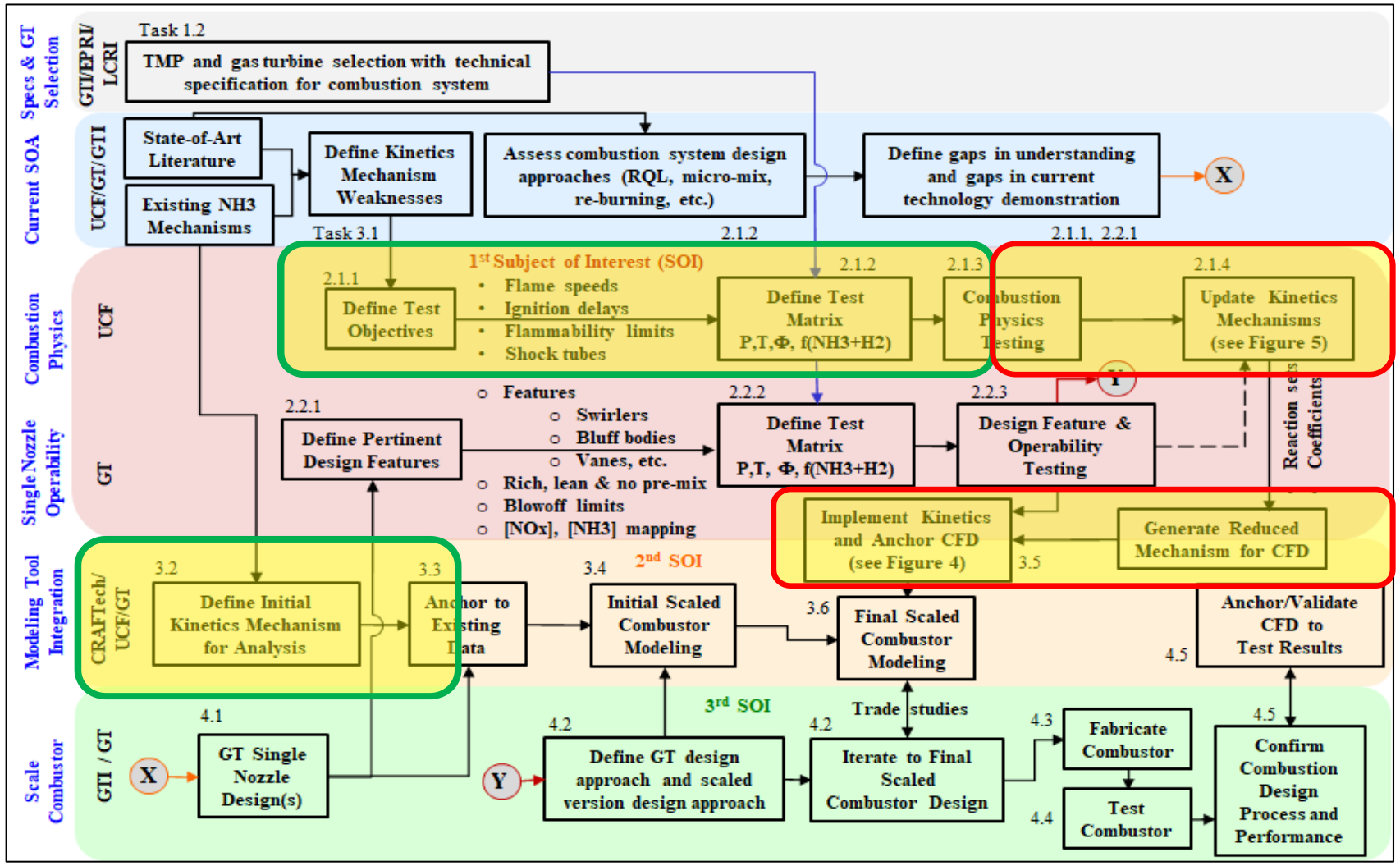
- Challenges with ammonia
  - Safety considerations with ammonia
  - Ammonia kinetics, ignition and flame-holding
  - NOx generation

Total DOE Project Value ~$ 3.75M including $750K LCRI cost share

Project Team Members

- **University of Central Florida** – Over 90 publications of high-fidelity molecular dynamics of combustion reactions research used to develop kinetics of combustion derived by variety of fuels
  - Expertise in shock tube testing to develop ignition delay, reaction rate measurements, and species time-history measurements using absorption diagnostics
- **Georgia Tech University** - Dedicated 50,000 square foot, $30 million combustion test facility
  - Expertise in experimental investigation of flame anchoring, acoustics, emissions, performance, and kinetics of a combustor at elevated pressures and temperatures
- **CRAFT Tech** – Developers of multi-element, unstructured CRUNCH CFD code used to perform complex analysis with chemical kinetics and particle modeling
  - Knowhow in developing species specific kinetics mechanism for combustion CFD based on experimental shock tube testing

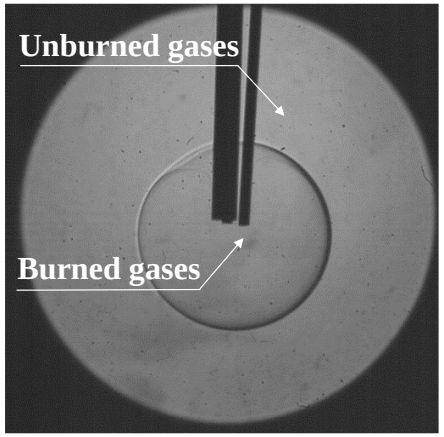
LCRI Power Gen Initiated Multiple Tasks Prior to DOE Award

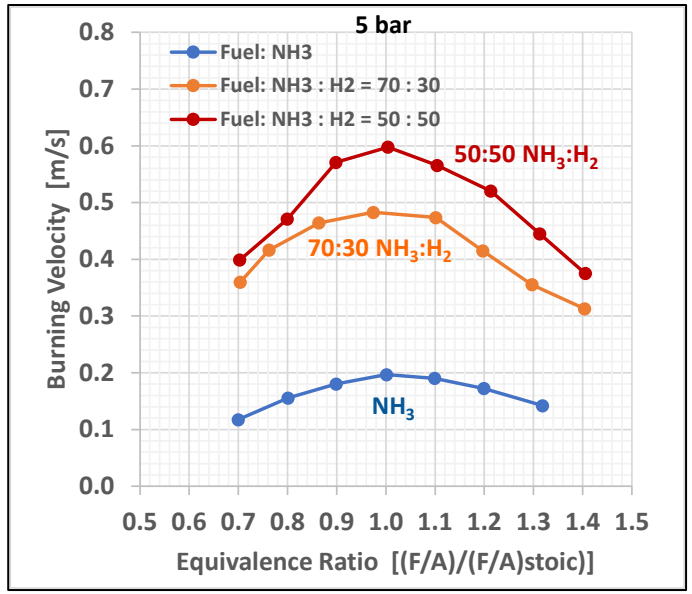


- Yellow = LCRI project - testing at UCF plus CFD at CRAFT Tech
  - Green border completed under LCRI
  - Red border scope transferred to DOE contract

Burning Velocity Testing Results (LCRI Effort)

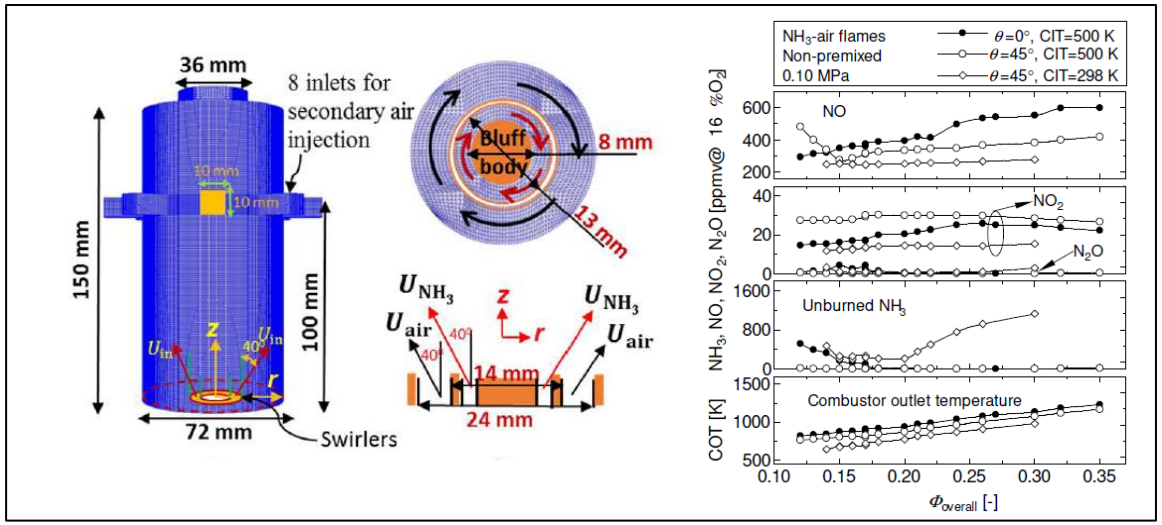
- UCF spherical, constant volume test rig for burning velocity tests
  - Schlieren diagnostics
- 5 bar with three different NH_3:H_2 blends completed
- Expected trend of increased flame speed with increased H_2 content
- Compared to kinetics mechanism predictions





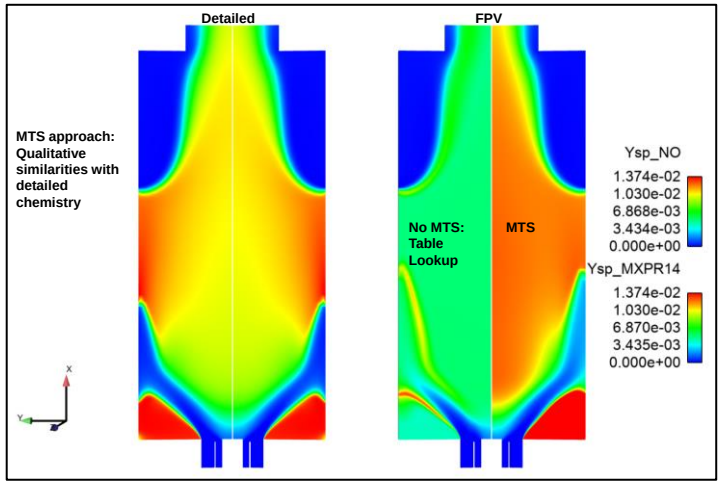
CRAFT Tech CFD Analyses Tasks Completed

- Sample case defined and model generated using UCF_LCRI.mech
  - Tohoku University tests
  - Exhaust emissions data available
- 2-D axisymmetric model generated in CRUNCH CFD© with MTS-FPV approach
  - Swirl non-premixed NH_3 and air at stoichiometric conditions



Okafor, E.C., Somarathne, K.D., Hayakawa, A., Kurata, O., Iki, N. and Kobayashi, H., "Towards the Development of an Efficient Low-NOx Ammonia Combustor for a Micro Gas Turbine", Proceedings of the Combustion Institute, Volume 37, Issue 4, 2019, Pages 4597-4606.

- Detailed mechanism, two FPV and one MTS-FPV cases run
  - Areas for improved FPV approach identified
- Emissions results reasonable compared to data



FPV = Flamelet Progress Variable
MTS = Multi-Time Scale

Parameter	CFD (Raw)	CFD (at 16% O_2)	Test Data (at 16% O_2)
Temperature [K]	1209	1209	~1100
NO [ppmv]	3065	730	~400
NO_2 [ppmv]	28.58	6.81	~29
N_2O [ppmv]	1.13	.27	~1

Path Forward

- LCRI project subcontracts terminated 9/1/22 (CRAFT Tech) and 9/9/22 (UCF)
  - Final report to be submitted by 10/15/22

- Remaining LCRI project scope included in DOE project
  - Complete UCF flame speed and IDT testing at higher pressures
  - Complete UCF shock tube IDT testing at higher pressures with laser diagnostics
  - Update detailed kinetics mechanism to better match data
  - Generate reduced mechanism for CFD analysis
    - Re-run CFD analysis case with updated mechanism

- DOE project to expand on LCRI work with burner design and testing

Questions?