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Investigation of Ammonia for Combustion Turbines (IACT) - Summary DE-FE0032172

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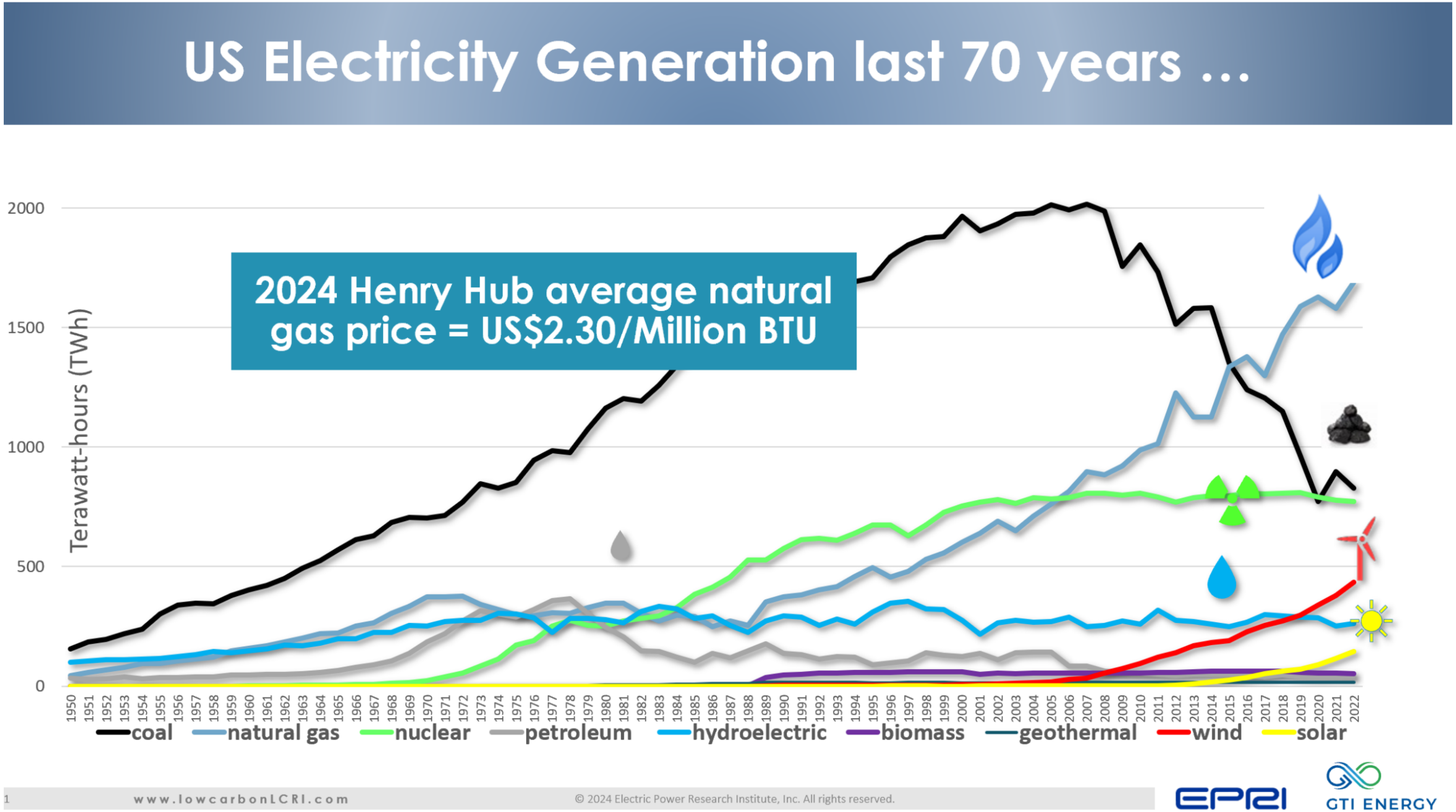
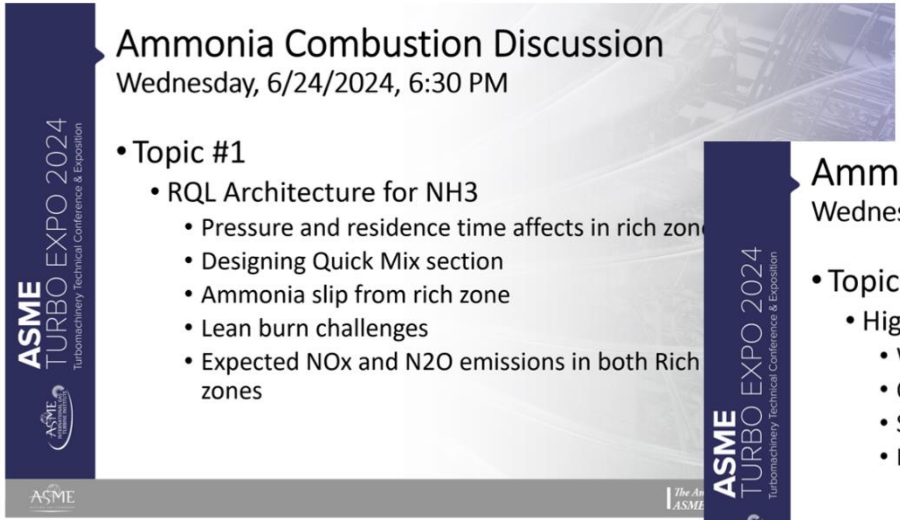
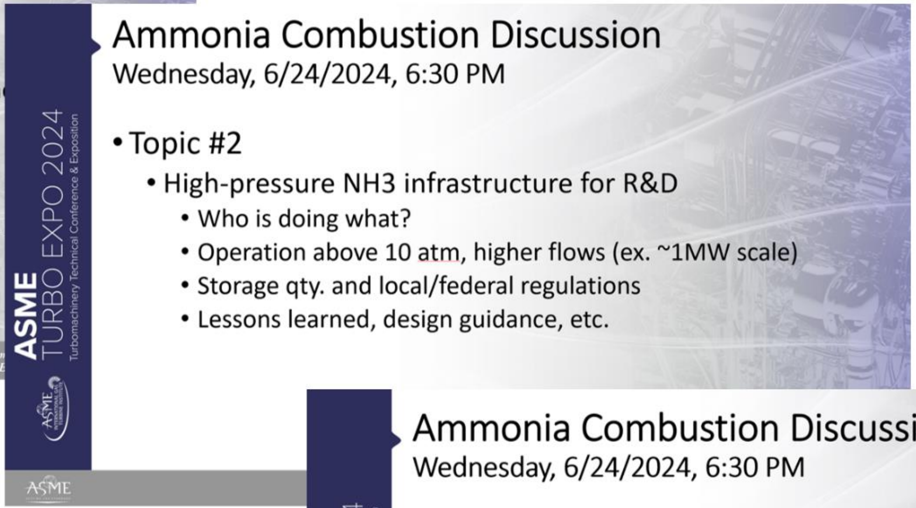
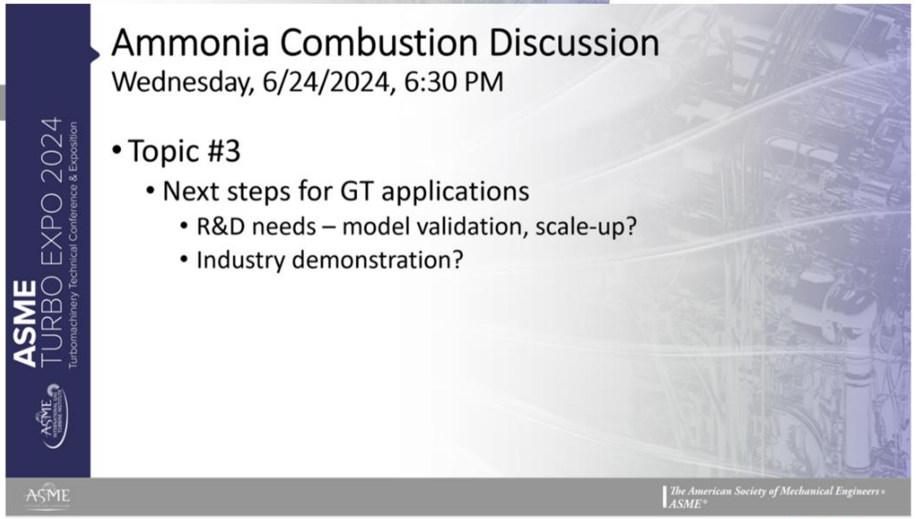
U.S. Power Generation Market



Ammonia Combustion Discussion in London







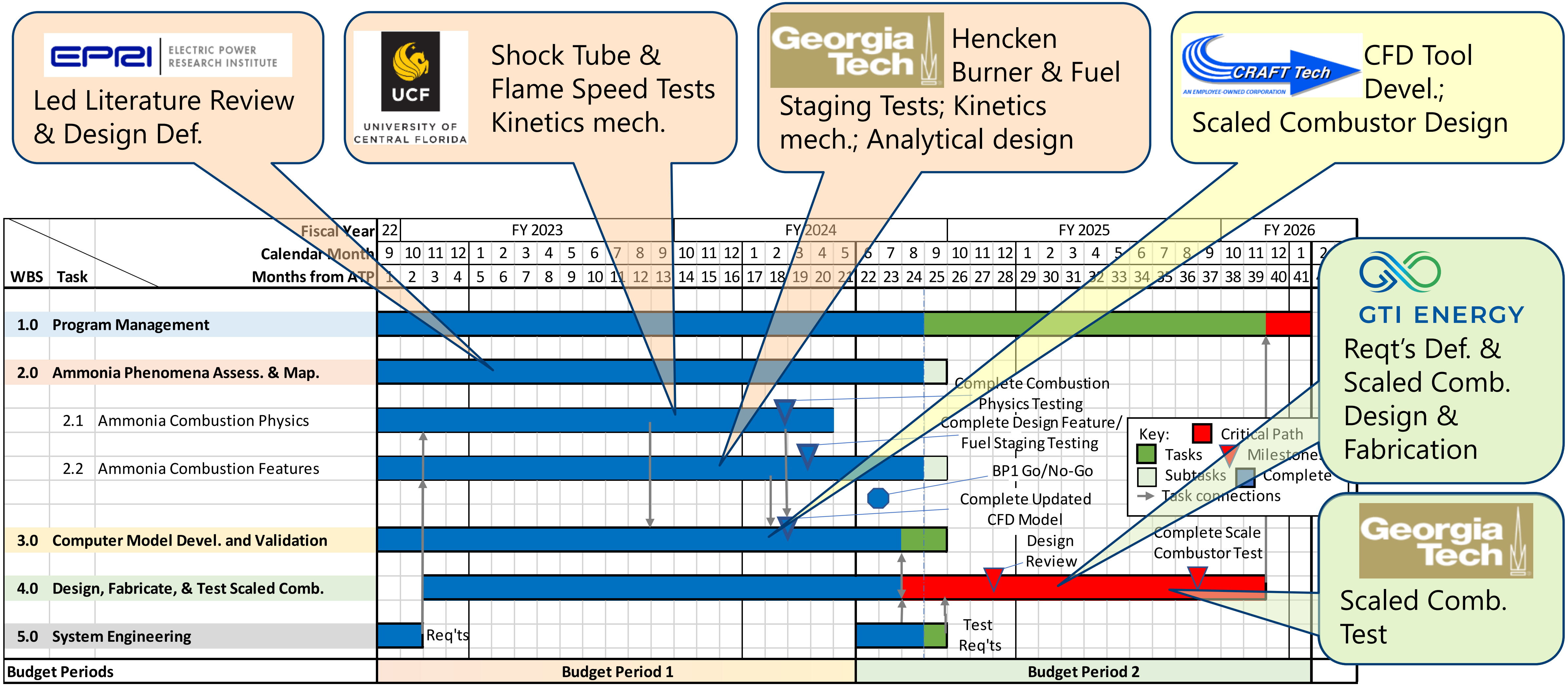
Investigation of Ammonia for Combustion Turbines (IACT)

- Goal - develop advanced combustor technology to utilize ammonia as a zero-carbon fuel for power generation applying an iterative physics, computational, and experimental approach resulting in a pilot combustor design validated through tests
- Goal: Test Scaled Combustor
  - Design using updated mechanism/ validated model
  - NOX Target: 20 ppm at 15% O_2
  - High combustion efficiency
  - Stable flame (no blowoff)
- Challenges with ammonia
  - Safety considerations with ammonia
  - Ammonia ignition and flameholding
  - NOx generation

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

Comparison of fuel characteristics

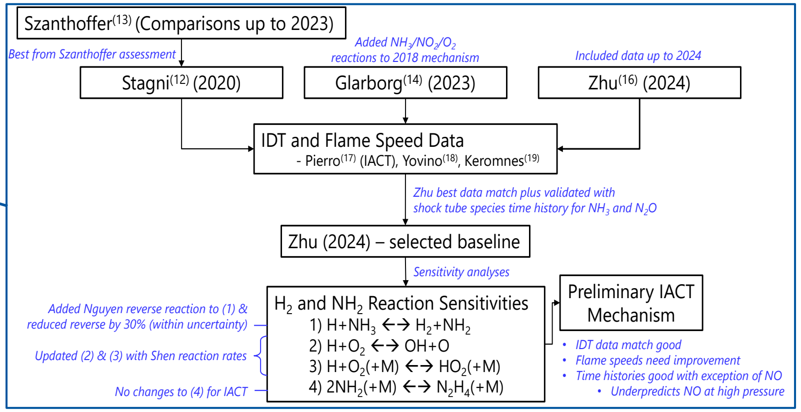
IACT Plan & Key Roles
Schedule: 9/2022-1/2026; Funding: $4.2M



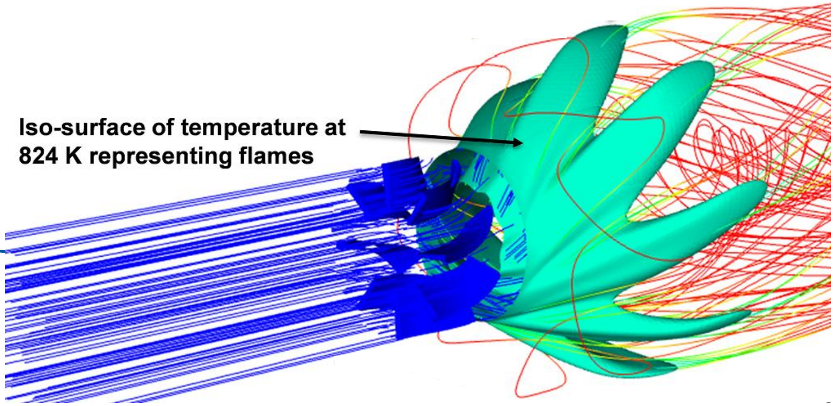
IACT Project Flow

NH_3 in fuel (%)	Phi	Pressure (atm)
50 -100	07 – 1.2	5-**20**

- ✓Literature search to understand SOA and identify knowledge gaps
  - ✓*Define test conditions to fill gaps*
- ✓Fundamental NH_3 & NH_3+H_2combustion physics testing
  - ✓*Generate improved detailed and reduced kinetics*
    - Will continue to improve



- Develop computational CFD design tool implementing updated mechanisms
  - –*Apply combustion physics knowledge and design tool*
    - ✓Applied to Primary (rich) zone
    - Extending to the Secondary (lean) zone
- Design and test scaled combustor - Ongoing



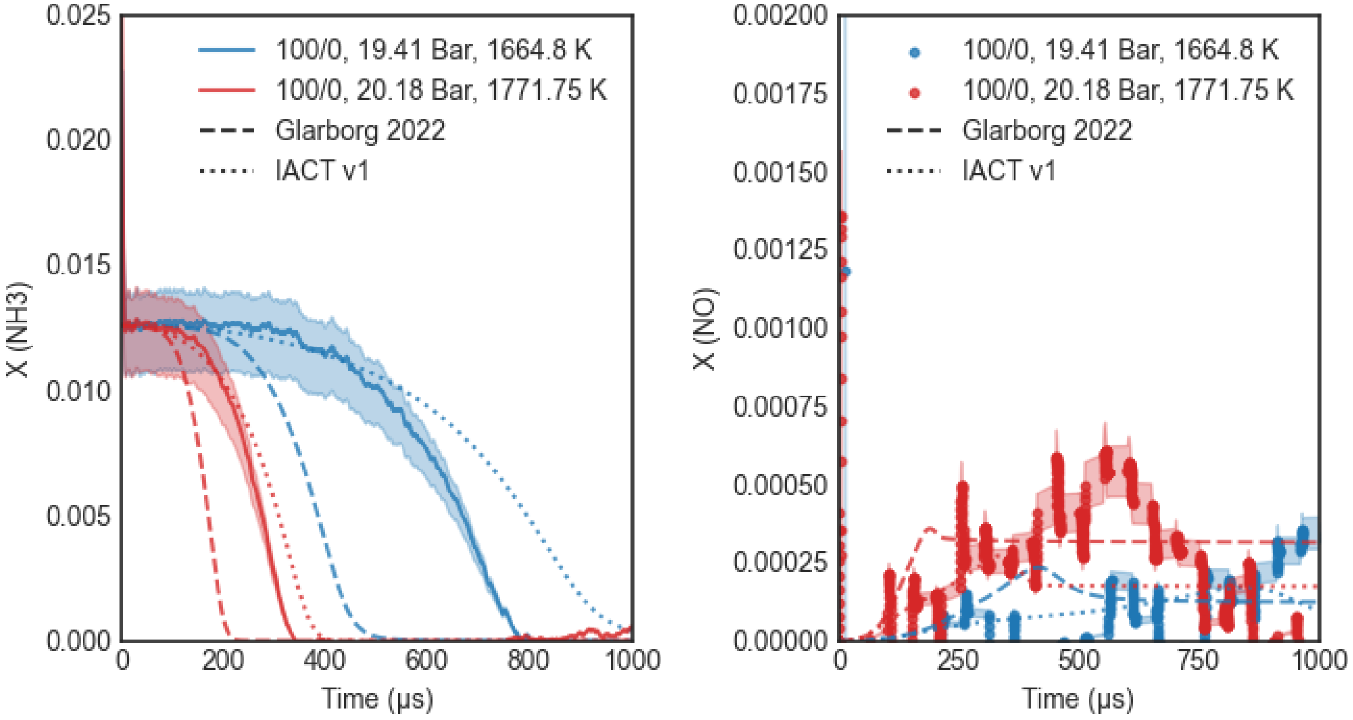
Completed Fundamental Physics Testing and Updated Kinetics Mechanism

- Discussed ongoing experiments and modeling in UTSR 2024
  - Range of conditions

NH_3 in fuel (%)	Phi	Pressure (atm)
50 -100	07 – 1.2	5-20

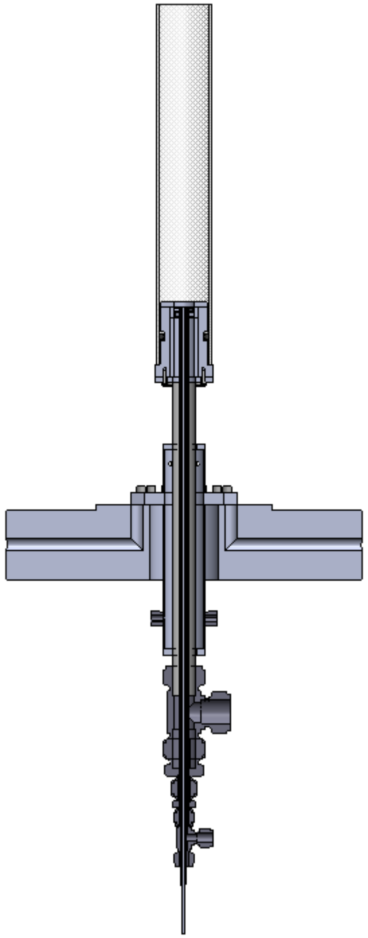
  - Flame Speed Measurements
  - Ignition Delay Times (IDT)
  - Species Cross-Sections/Time Histories
  - Developed Updated Kinetics Model
- Compared Model to Time Histories
  - Improved predictions in species time history measurements for pure NH_3 and the 70/30 NH_3/H_2 mixtures
  - Still need improvements when larger H_2 fractions are used

F =1.2, 100% NH_3, 20 Bar

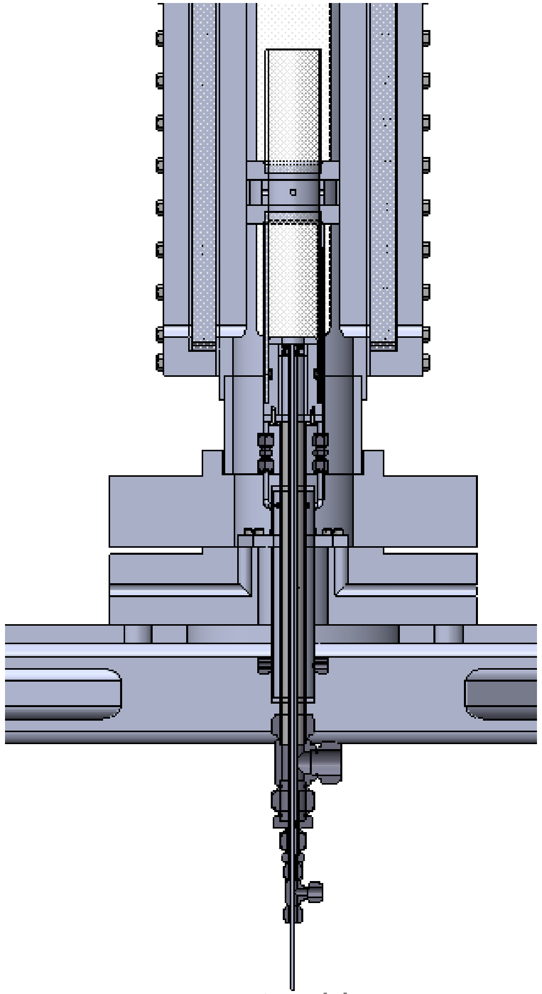


Example data from 81 plots across range of conditions

Prototype Swirl Burner Atmospheric/Pressurized Tests



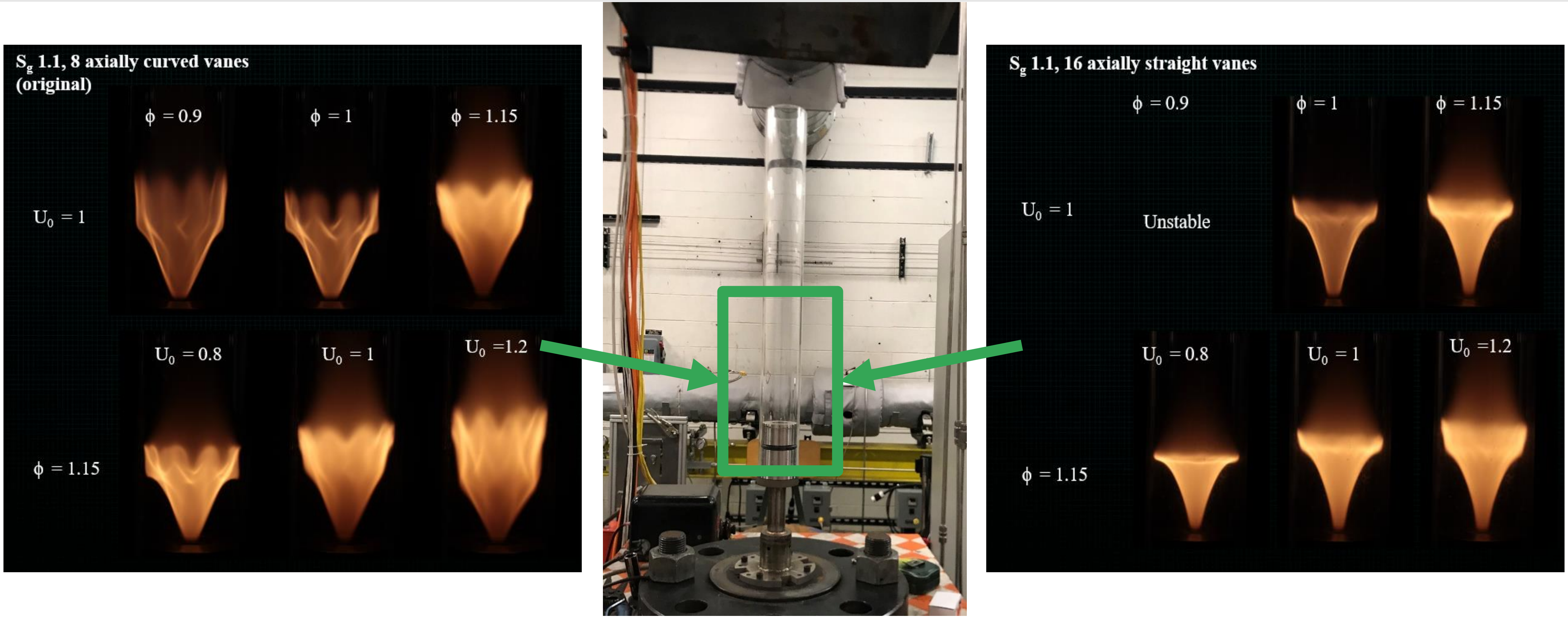
Atmospheric burner configuration



Pressurized burner configuration

- Small scale experiments will investigate flame stability, blow-off, and emissions
  - Various swirl/secondary air configurations
- Atmospheric testing is ongoing
  - Characterize the emissions profiles in the primary rich zone
  - Characterize emissions after air injection in the lean secondary zone
- Pressurized testing will begin in October
  - Same goals

Atmospheric/Pressurized Tests
Staging Tests – Burner Evaluation



- Undesirable wake structure in original swirl burner
- Evaluated multiple options and selected additional straight vanes, minimal lobes

Model (Adiabatic) vs. Test Data: NO and NH3 Aft of Rich Primary Zone

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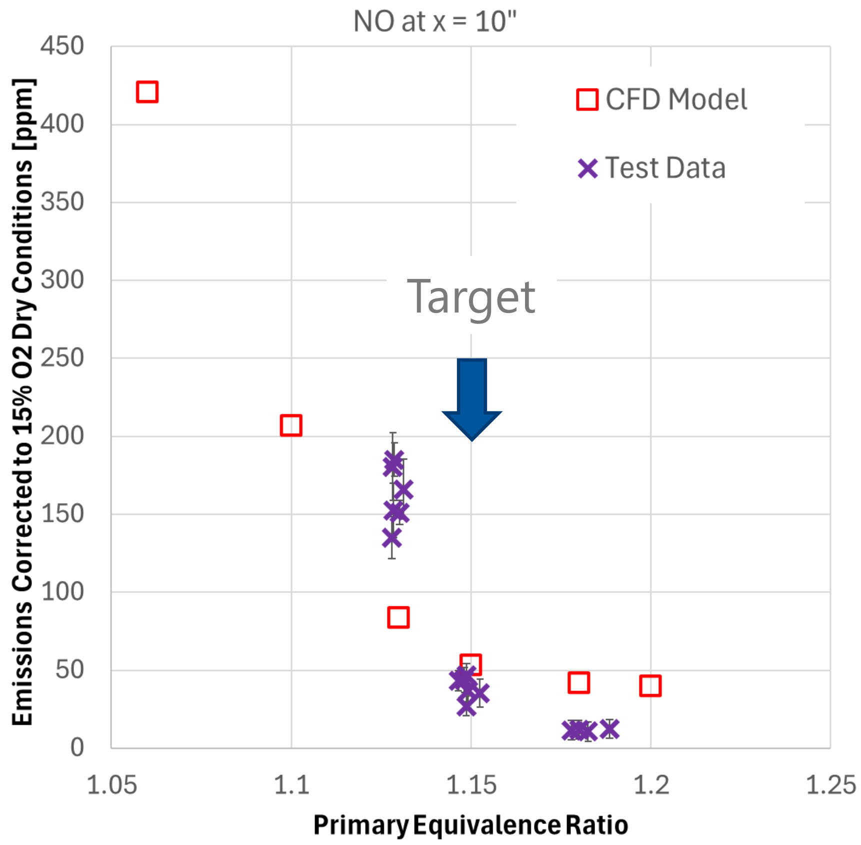
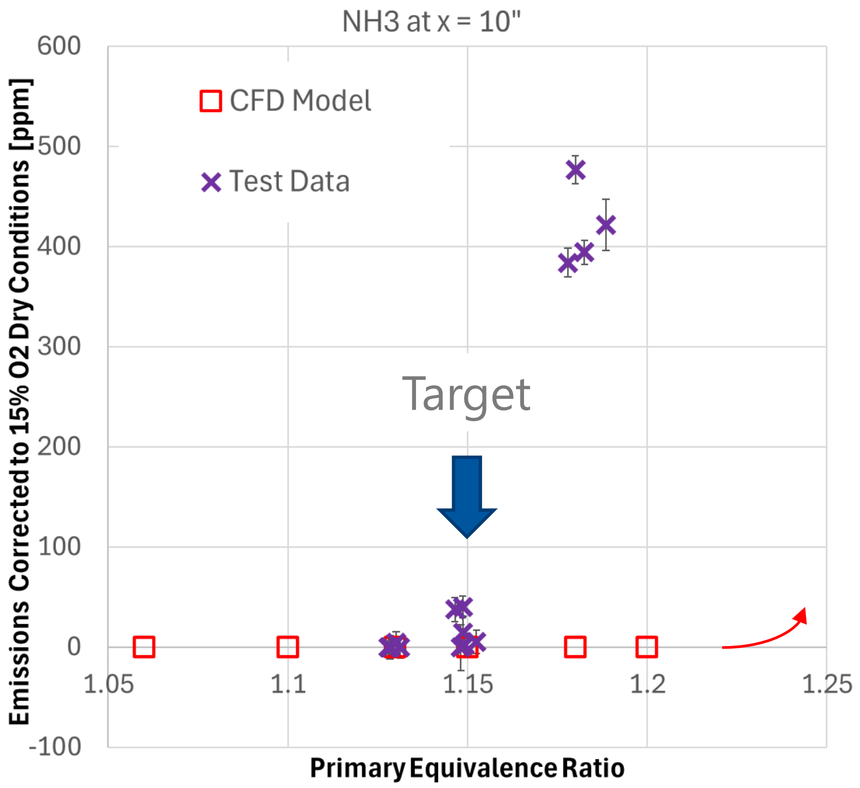
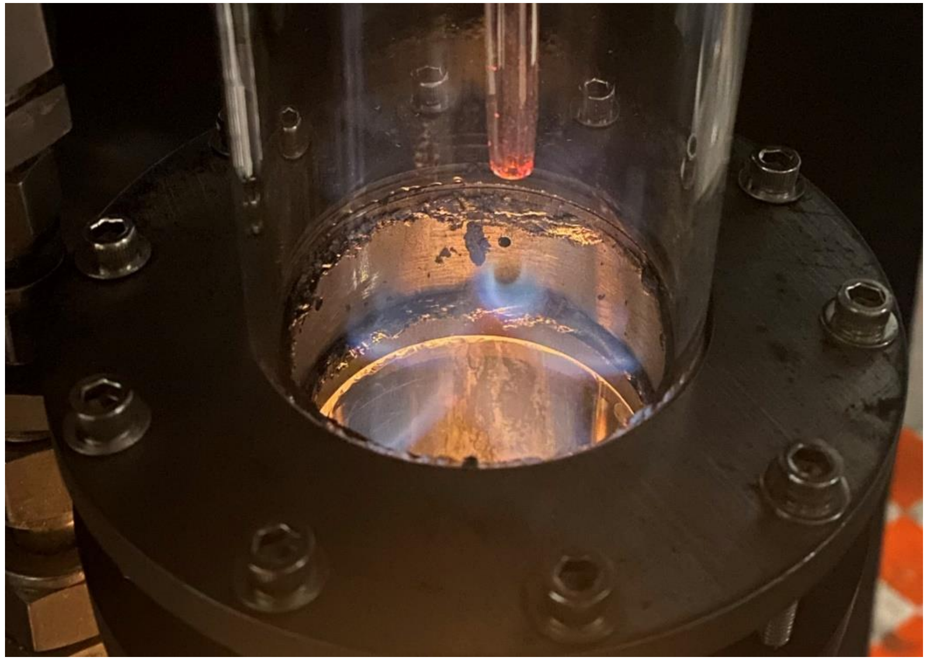




- Model matches NOx and NH_3 trends, some absolute values need work
- Leanest E.R. – excess NO; Richest E.R – excess NH_3: Targeting Primary E.R ~ 1.15
- NO and NH_3 very sensitive to ER and heat loss

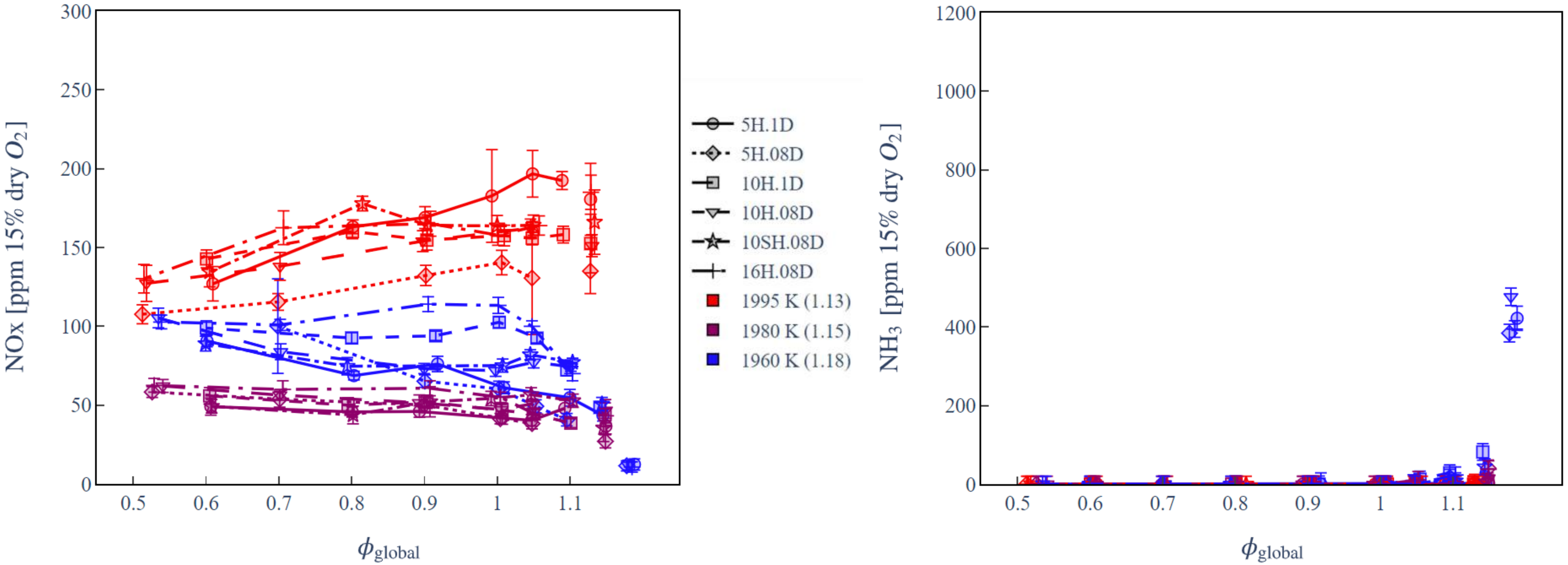
Staged Combustion Testing with Prototypic Swirl Burner/Air Injection

- Atmospheric Pressure
- Primary E.R. – 1.13 to 1.18
- Global Phi = 0.5 to 1.14
- Primary swirl burner
  - Sg = 1.1 swirl number
  - 16 vanes
- Secondary Air
  - 5 or 16 holes
  - 0.08 to 0.10 inch diameter
- Planned CFD simulations for final design analysis:
  - Higher-fidelity than 1-D ROM with representation of flame structure and non-uniformities associated with mixing/reactions



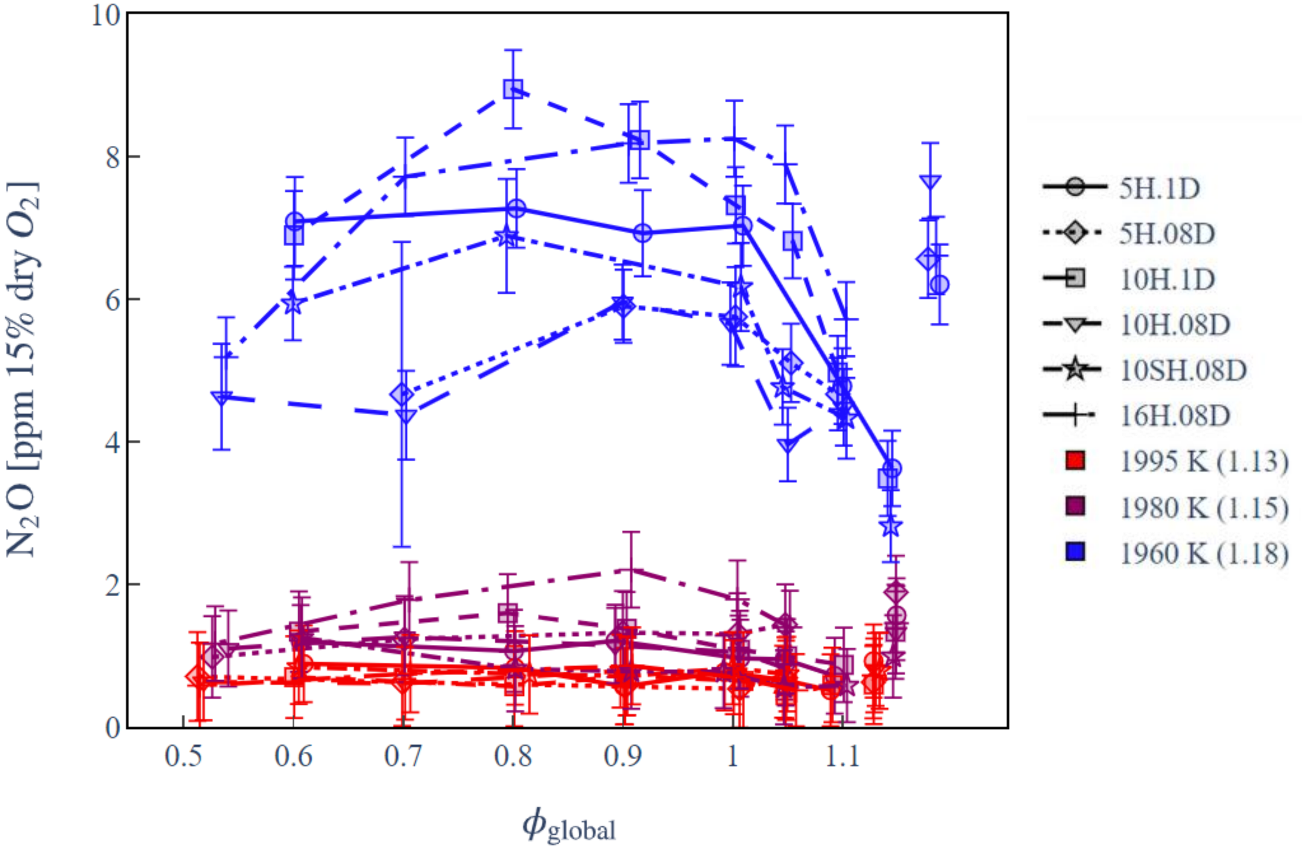
Secondary air injection with insulation removed (note point probe)

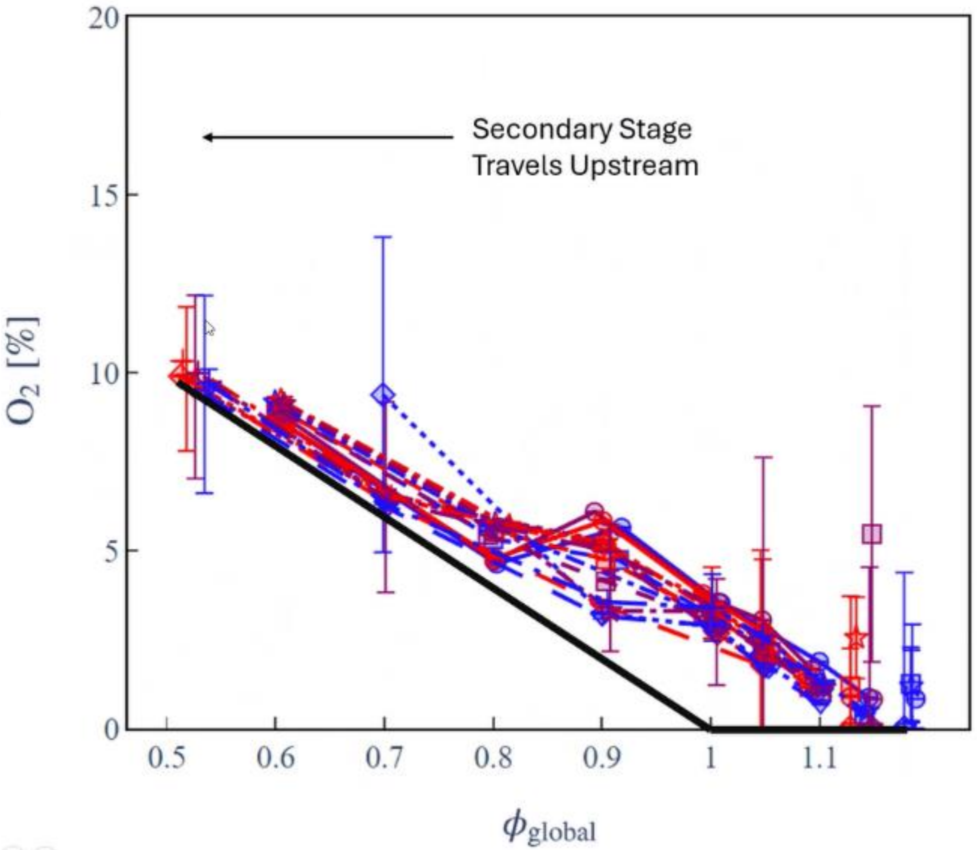
Staged Combustion Testing with Prototypic Swirl Burner/Air Injection (Cont'd)



- Keeping NH_3 slip low in primary zone, especially at low E.R.
- Achieving low NOx – 50-60 ppm 15% dry O_2 – at optimum primary E.R. @ Atm. pressure
- Note: Non-monotonic NO_x trend with $\Phi_{primary}$

Staged Combustion Testing with Prototypic Swirl Burner/Air Injection (Cont'd)





- N_2O is low, particularly at E.R. = 1.13
- Approaching theoretical oxygen levels at gas turbine conditions

Summary/Next Steps

- Executing a 41 month, $4.2M project to advance NH_3 combustion technology
  - Ammonia is an alternative low-carbon energy carrier
  - Recently began Budget Period 2
- Ammonia combustion physics testing is complete (UCF) over a range of relevant gas turbine conditions to fill in high pressure data
- Prototypic combustor tests ongoing (GTRC)
  - Achieved 50-60 ppm (15% dry O_2) at atmospheric pressure - ~5 bar next
- Refining CFD models and will employ in the Scaled Combustor design
- Ongoing preparations for larger, higher pressure Scaled Combustor test at GTRC

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