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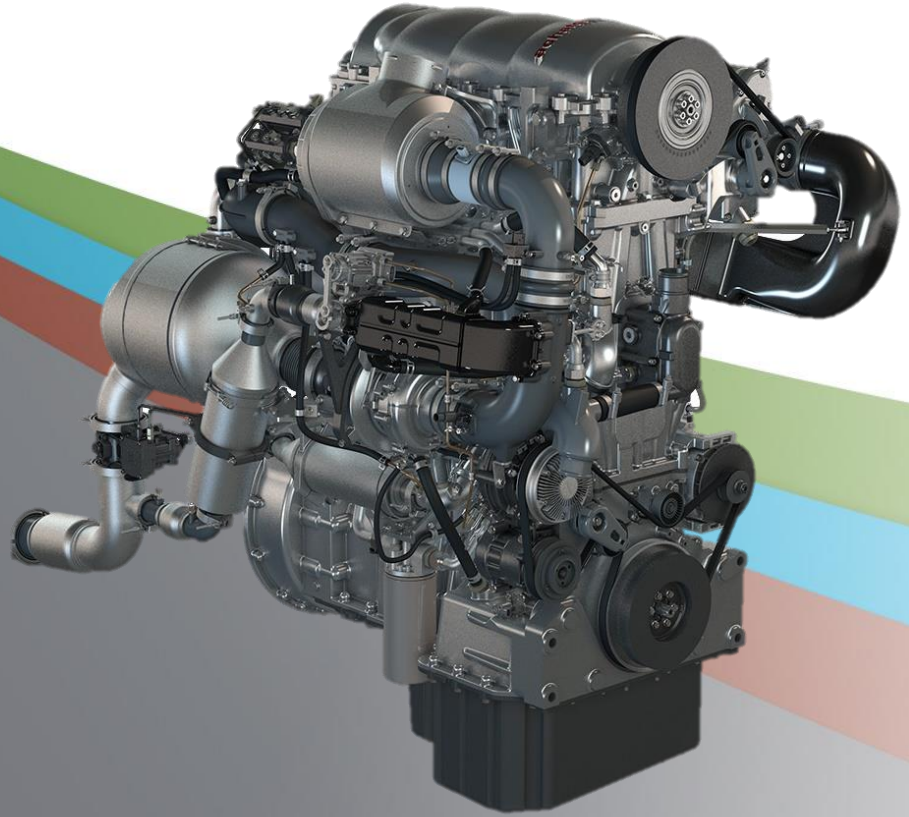

Opposed-Piston 2-Stroke Hybrid Commercial Vehicle System

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Overview

Timeline

- Start: March 2022
- End: May 2024
- Completion 10%

Budget

- Total project funding $6.25M
- DOE: $5M
- Cost share: $1.25M

Barriers

- Achieving ultra low criteria emissions adds significant powertrain cost
- Achieving ultra low criteria emissions causes an increase in CO_2 emissions
- The use of carbon based fuel contributes to green house gas emissions

Partners

- Isuzu Technical Center of America
- Clemson University
- University of Wisconsin - Madison

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Relevance

- Impact:
  - The opposed piston engine has demonstrated the ability to meet the future emissions regulation, more that 10% lower fuel economy and lower system cost than other solutions.
  - This project will enable further CO_2 reductions while still meeting the future emissions with hybridization.
  - The second part of this project is to explore hydrogen combustion in the opposed piston engine to bridge the technology into a low carbon emissions world.

- Objectives:
  - Demonstrate advanced opposed-piston ("OP") engine technology for commercial vehicle applications with hybridization that significantly improves energy efficiency and reduces emissions over conventional powertrains.
  - Optimize engine and hybrid propulsion system design and calibration to minimize CO2 emissions while meeting ultralow NOx regulations
  - Investigate use of sustainable and renewable fuels in the OP hybrid engine system

Milestones

Milestone (status)	Quarter	Description
Steady state ULNOX engine and aftertreatment model data generation	June, 2022	Experimental data (engine out, tailpipe out) over steady state conditions has been collected for engine and aftertreatment model development.
Transient ULNOX engine and aftertreatment model data generation	Sept, 2022	Experimental data (engine out, tailpipe out) over transient conditions has been collected for engine and aftertreatment model development.
Diesel combustion CFD optimization	Dec, 2022	Combustion CFD optimization will suggest a piston bowl and fuel injector configuration at hybrid relevant operating conditions for a multicylinder OP engine.
Engine and aftertreatment system models for hybrid system simulation have been developed (Go/NoGo)	March, 2023	Engine and aftertreatment models have been developed. Hybrid simulation results will predict fuel economy and tailpipe out emissions within 10%
Supervisory and model predictive control development complete	June, 2023	Supervisory and model predictive controls considering efficiency and tailpipe emissions for the OP engine in a hybrid powertrain are completed and ready to implement for engine-in-the-loop testing.
Diesel multicylinder engine-in-the-loop testing round 1 completed	Sept, 2023	Engine-in-the-loop testing with the OP engine powering a virtual hybrid powertrain has been completed.
Low load cycle control development complete	Dec, 2023	Controls for low load CO2 and tailpipe NOX optimization have been completed and are ready for engine-in-the-loop validation.

Approach

- Collect steady state and transient data from the 10.6L heavy duty opposed piston engine capable of achieving future emission levels to build an engine and aftertreatment model.
- Build the powertrain model using the data collected.
- Use the model to define the optimal hybrid system configuration.
- Optimize the combustion system for the specific hybrid operating range.
- Develop supervisory controller to test with the engine in the loop.
- Perform too rounds of engine in the loop testing to demonstrate at least 13% CO2 improvement over the non-hybrid version.
- In parallel perform analysis to define the best approach to burn hydrogen in the opposed piston engine.
- Procure hydrogen combustion system components and test hydrogen combustion on a single cylinder engine.

Approach:
Starting point: Heavy Duty 10.6L OP Engine

- First Generation 10.6L OP HD engine, 400hp 2200Nm
- Running at CARB 2027 emissions levels with single underfloor aftertreatment system
- Used in fleet service since November 2021 in Peterbilt 579
- 10+% fuel economy advantage over 2021 reference 4-stroke vehicle from fleet measurements.
- 30% margin to 2030+ in-use CARB NOx standards, per PEMS measurements by University of California Riverside

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Technical Accomplishment and Progress: Second Generation Engine and Aftertreatment

Air system improvements:

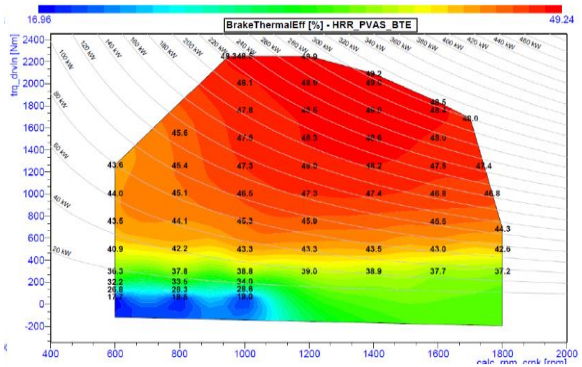
- SuperTurbo driven turbocharger:
- Eaton EGR Pump: Provides independent EGR control

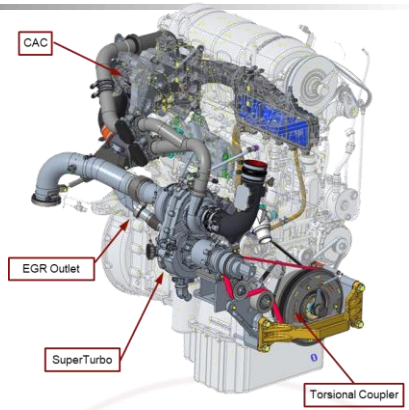
Various Friction improvements:

- Lower friction rings, cylinder material and honing process improvements and lower viscosity oil

Aftertreatment system improvements:

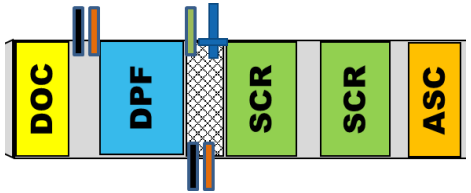
- Conventional DOC, DPF, SCR, still underfloor only
- BASF catalyst formulations, Corning substrates, Eberspaecher insulated can





Project testing started:

- Measured results compared to first generation:
  - Steady state and initial transient engine data was collected
  - 49.2% best point BTE vs 47.1%
  - 5% lower CO_2 on SET, 8% lower on Hot FTP
  - 30% higher exhaust heat generation for catalyst light-off mode
  - Higher and Narrower exhaust temperature range



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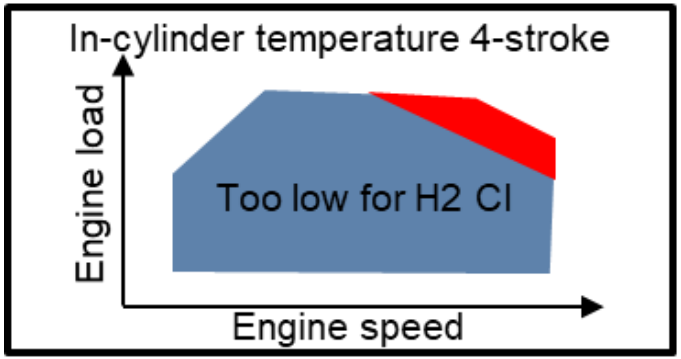
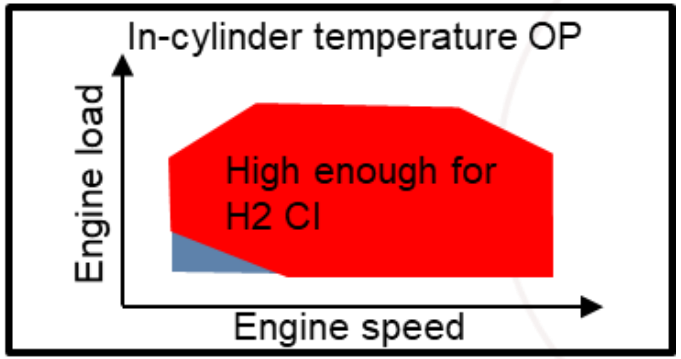
Technical Accomplishment and Progress: Combustion Approach Selection for OP Hydrogen

- Opposed piston engine enables compression ignition with trapped temperature control:
  - Most efficient diesel like combustion process without ignition assistance (H2 Compression ignition (CI) diffusion flame) → Preserves or improves upon the efficiency of the OP diesel engine and no compromise in engine capability.
  - Spark ignition (SI) will be used on initial start and low load operation
  - Direct injection variable pressure





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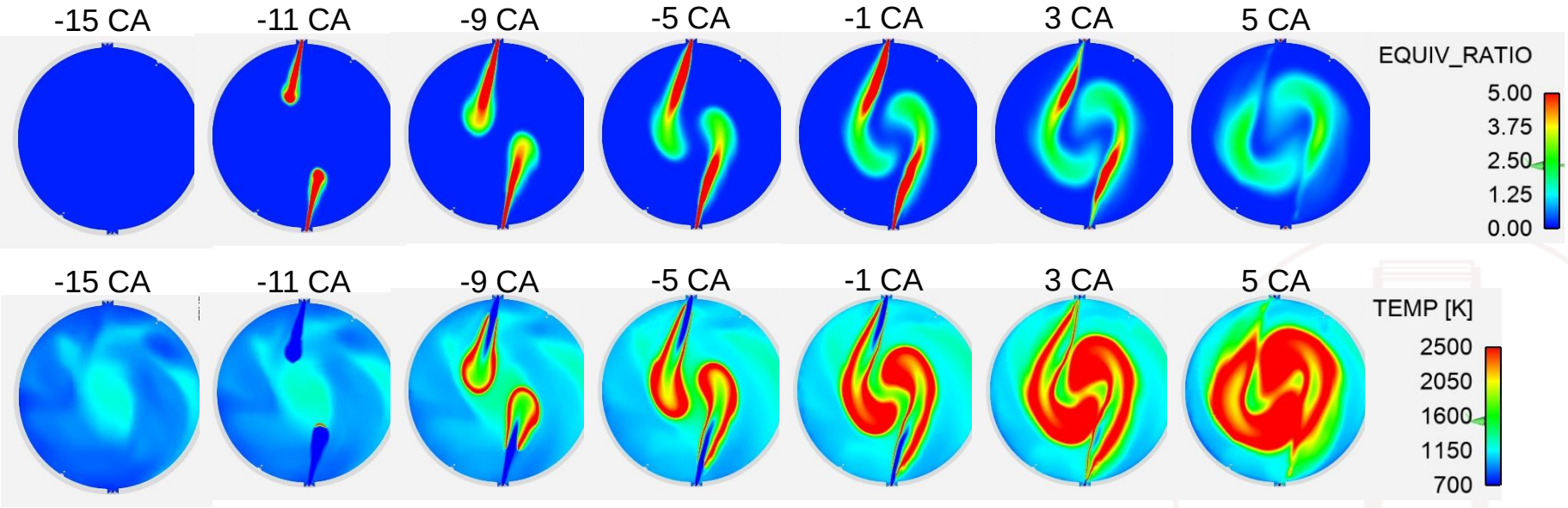
Technical Accomplishment and Progress: Compression Ignition Combustion CFD – High Speed High Load



H2 Injection at -11CA, no ignition assistance, note the hot residual zone in center

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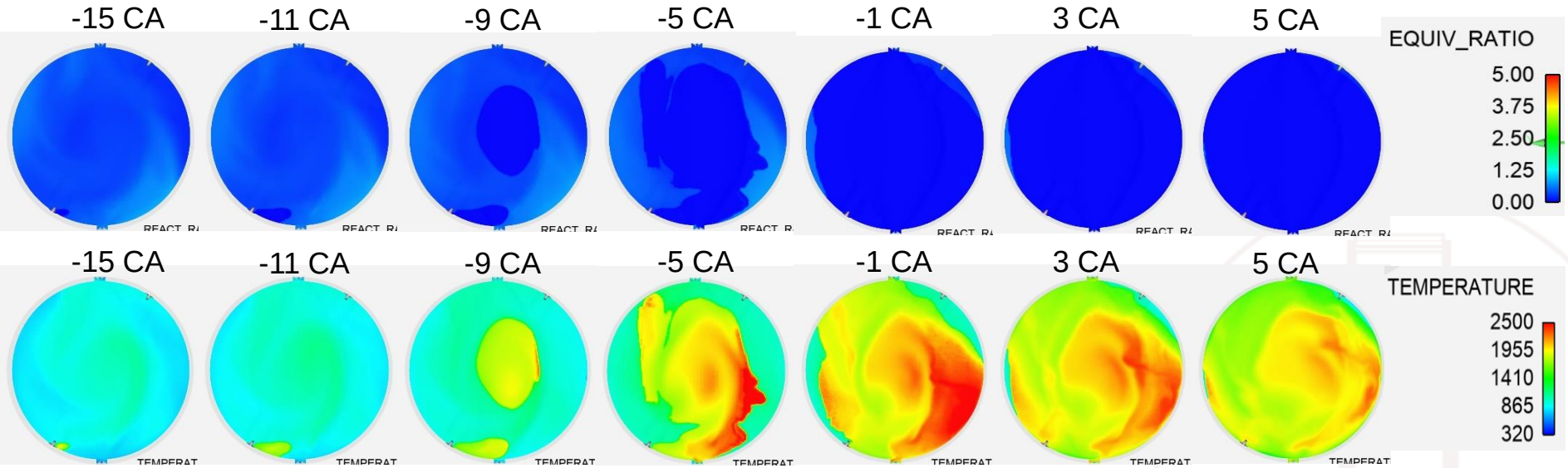
Technical Accomplishment and Progress: Spark Ignition Combustion CFD – Low Speed Low Load



H2 Injection early in the compression cycle, spark ignition at -15CA

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Collaboration and Coordination with Other Institutions

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Prime, industry

- Test 10.6L heavy duty engine, design and procure hardware
- Test single cylinder on hydrogen, design and procure hardware

ISUZU

Sub, industry

- Provide technological choices feedback
- Support vehicle system analysis

CLEMSON UNIVERSITY

Sub, university

- Engine and aftertreatment modelling
- Hybrid powertrain analysis
- Supervisory hybrid controller for engine in the loop testing

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

Sub, university

- 3D CFD combustion simulation
- CFD piston bowl optimization

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Proposed Future Research

FY22

- Collect engine and aftertreatment data
- Build engine and aftertreatment model
- Define hybrid powertrain layout
- Start supervisory model development
- Start diesel combustion system optimization for hybrid operation
- Define hydrogen combustion approach
- Design and procure hydrogen combustion system components for single cylinder engine.

FY23

- Test the hybrid powertrain with the supervisory control model and the engine in the loop
- Correlate models and further improve the combustion system and the hybrid controls
- Test single cylinder engine on hydrogen to corelate combustion models
- Use first round of testing results to improve hydrogen combustion system
- Procure second round of hardware for Hydrogen testing and test

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

Summary Slide

Accomplishments

- Started collecting steady state and transient engine data
- Selected the mode of combustion for hydrogen and performed combustion CFD studies

Relevance toward VTO objectives

- The engine data collected is used for the hybrid model development that will be used to optimize and select the hybrid powertrain
- Combustion CFD is used to select the engine configuration for the hydrogen testing
- Hydrogen is a renewable, sustainable and carbon free fuel.