ENERGETICS

FPT Industrial - Fueling the Future: Hydrogen, Natural Gas, and Ethanol for Clean Heavy-Duty Combustion

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Context of the research activity	In the transition toward sustainable transport, the heavy-duty sector presents specific challenges that cannot be fully addressed by battery-electric solutions due to range, refueling time, and payload constraints. For this reason, alternative fuels that are compatible with internal combustion engines (ICEs) are gaining attention as pragmatic enablers of short- and medium-term decarbonization. Among these, hydrogen, natural gas, and ethanol represent three promising but fundamentally different options. Hydrogen is carbon-free and enables near-zero CO2 emissions at the tailpipe. Natural gas is widely available, offers favorable CO2 performance compared to diesel, and benefits from mature infrastructure and engine technologies. Ethanol, especially when produced from renewable sources, is a bio-based fuel with high octane number and favorable combustion properties for high-efficiency spark-ignition operation. Despite their advantages, these fuels differ significantly in terms of ignition characteristics, flame propagation, heat release, and pollutant formation, particularly under the high-load, high-pressure conditions typical of heavy-duty engines. Understanding these behaviors through high-fidelity simulation is crucial to fully unlock their potential. Advanced CFD combustion modeling offers a powerful approach to explore these effects, reduce experimental development time, and support optimized engine design. However, a systematic and comparative numerical investigation of these three fuels under engine-relevant conditions remains a key research gap.

	The main goal of the proposed PhD project is to develop and validate detailed and fuel-specific CFD combustion models for hydrogen, natural gas, and ethanol, aimed at supporting the development of high-efficiency, low-emission heavy-duty engines. The research will include: • Selection and validation of chemical kinetic mechanisms specific to hydrogen, methane-based fuels, and ethanol, with attention to key combustion phenomena such as ignition delay, flame speed, knock tendency, and pollutant formation (e.g. NO¿, CO, unburned hydrocarbons). • Implementation of detailed and reduced mechanisms in 3D CFD platforms (e.g., CONVERGE CFD or equivalent), with treatment of turbulence-chemistry

Objectives	interaction and wall heat transfer. • Simulation of combustion in realistic engine geometries, under a variety of operating conditions, including PFI and DI injection strategies, lean and stoichiometric mixtures, and high-load transients. • Comparative analysis of combustion performance, emissions, and abnormal phenomena (e.g., knock, pre-ignition, misfire) for the three fuels. • Support for the definition of optimized combustion strategies, enabling clean and efficient use of each fuel in future engine platforms. This project will provide robust simulation-based insights to guide the technology-neutral selection and development of low-carbon fuels for heavy-duty transport.

Skills and competencies for the development of the activity	• Excellent knowledge of fluid-dynamics and engine thermodynamics • Knowledge of 1D/3D CFD simulation codes (such as GT-SUITE, CONVERGE CFD)