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Letter from the Guest Editors

Focus Issue on Low-Carbon Fuels for Sustainable Transport

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The urgent need to reduce greenhouse gas (GHG) emissions has placed the transportation sector at the forefront of global climate action. While electrification is advancing rapidly for passenger vehicles, commercial, off-road, marine, and aviation sectors will continue to rely on liquid and gaseous fuels for the foreseeable future. In this context, the transition to low-carbon fuels—including natural gas, biofuels, synthetic fuels, e-fuels, methanol, ethanol, hydrogen, and ammonia—offers a critical pathway to decarbonize transport while leveraging existing infrastructure and technologies.

This focus issue, entitled “Low-Carbon Fuels for Sustainable Transport”, brings together eight original research papers that collectively address the technological, environmental, and practical challenges of low-carbon fuels for sustainable transport. The selected papers reflect the multifaceted dimensions of the field, spanning cradle-to-gate life cycle analysis (LCA), techno-economic analysis (TEA), and kinetic and computational modeling of low-carbon fuel, advanced combustion and fuel utilization strategies, waste heat recovery, and fuel production pathways. These studies provide new insights into the integration of low-carbon fuels in heavy-duty vehicles, agricultural machinery, and power generation, highlighting both the opportunities and challenges in achieving meaningful emissions reductions.

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The first three articles used LCA to evaluate the environmental effects of producing and using low-carbon fuels.

McCord et al. examined pathways for increasing sustainable aviation fuel (SAF) yields by upgrading CO_2 at corn ethanol plants. The study compares the alcohol-to-jet upcycling route and Fischer–Tropsch synthesis, evaluating the environmental impacts of CO_2 conversion to ethanol using a fermentation process and subsequent upcycling to SAF. Results indicate that CO_2-to-SAF pathways can substantially reduce the carbon footprint compared to bioethanol upcycling. The research highlights the need to transition away from corn-based feedstocks and quantifies the benefits of CO_2 to CO conversion using solid oxide electrolysis. The findings inform future SAF production strategies and support the development of low-carbon aviation fuels.

Kim et al. assessed the energy consumption and life cycle environmental impacts of H_2-based powertrain technologies for large agricultural tractors, in comparison with other alternative technologies. The study compares series, parallel, power split hybrid electric, fuel cell, battery electric, and H_2 internal combustion engine powertrains across various duty cycles. Results indicate that H_2 fuel cell and battery electric powertrains offer significant long-term GHG reduction potential when paired with renewable energy, while H_2 engines provide practical intermediate solutions. The research offers valuable insights into the benefits and challenges of integrating alternative fuels and powertrains in agricultural machinery for sustainable agriculture.

Mu et al. evaluated the cradle-to-gate GHG emissions of H_2 fuel cell heavy-duty vehicles in China, analyzing three size classes and driving ranges. The study identifies fuel cell and H_2 storage systems as major contributors to emissions, with platinum, titanium, carbon black in the catalyst and bipolar plate, and carbon fiber–reinforced polymer (CFRP) layer being particularly significant. The research highlights the importance of grid decarbonization, reduced platinum loading, and lightweight materials for emission reduction. The findings provide actionable strategies for minimizing the environmental impact of H_2 fuel cell vehicles and inform future design and manufacturing practices for sustainable transport solutions.

The second set of five articles examined the flow, combustion, and utilization of low-carbon fuels in engines and power generators.

Torelli et al. investigated the behavior of high-pressure H_2 flows through single- and multi-hole nozzles, relevant to H_2 injection systems in internal combustion engines. Using validated computational fluid dynamics simulations, the authors analyze the effects of ambient gas composition, temperature, turbulence models, and grid strategies on H_2 flow characteristics. The study provides best practices and guidelines for researchers and industry professionals seeking to optimize H_2 injector design and performance. The findings contribute to overcoming technical challenges in H_2-fueled engines and support the advancement of H_2 as a viable low-carbon transport fuel.

Cai et al. investigated the combustion characteristics of ammonia/n-heptane mixtures in dual-fuel engines, focusing on ignition delay and reaction kinetics. Rapid compression machine experiments measure ignition delays at varying ammonia fractions and temperatures, revealing the impact of ammonia content on combustion behavior. A reduced chemical mechanism is developed, accurately predicting ignition delay and laminar flame speed while significantly reducing computational time. The model is applied to three-dimensional simulations, effectively capturing combustion and emission trends. The study advances understanding of ammonia-diesel dual-fuel engines and supports the development of efficient, low-carbon combustion strategies.

Trzaska et al. presented a novel strategy for achieving mixing-controlled compression ignition (MCCI) with GrenOl (70% 1-butanol, 15% 1-hexanol, and 5% 1-octanol by mass), a sustainable ethanol-derived alcohol blend, in heavy-duty diesel engines. By employing an exhaust rebreathing valve strategy, the study demonstrates stable combustion and diesel-like emissions across the engine operating map, even at low cetane numbers. Experimental results show a low coefficient of variation in indicated mean effective pressure at idle and competitive fuel consumption and NO_x emissions at medium load. The research proves the feasibility of operating diesel engines on neat, renewable alcohol fuels with minimal modifications, advancing sustainable fuel integration in heavy-duty transport.

Gore et al. used a prototype high-power-density generator to operate on methanol fuel, evaluating its performance and emissions reduction potential. The generator, originally designed for lightweight applications, demonstrates increased peak power output and significant carbon emission reductions when fueled by methanol compared to gasoline. Experimental results highlight the feasibility of using renewable methanol in compact generators for range extenders, hybrid powertrains, and UAV propulsion. The study showcases the potential of methanol as a carbon-neutral fuel for high-specific-power applications, contributing to the broader adoption of sustainable fuels in power generation.

Sok and Kusaka explored the use of thermoelectric generators (TEG) for waste heat recovery (WHR) in compressed natural gas (CNG) heavy-duty truck engines. Through experimental and 1D-CFD modeling, the authors demonstrate that integrating TEGs with heat exchangers can improve thermal efficiency and generate electrical power from exhaust heat. Engine experiments and simulations reveal that a compact TEG-WHR system can enhance brake thermal efficiency by up to 1.07%. The research provides valuable insights into optimizing TEG design and integration for commercial natural gas vehicles, contributing to improved energy utilization and reduced emissions in heavy-duty transport.

By presenting cutting-edge fundamental research on low-carbon fuel flow and combustion, SAF production, and their applications for agricultural tractors, fuel cell vehicles, heavy-duty trucks, and generators, this issue advances our understanding of how low-carbon fuels can be effectively deployed across diverse applications. The findings inform future research, policy, and industry practices, supporting the transition to a more sustainable, efficient, and environmentally friendly transportation system.

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