Chapter 1
Introduction to Renewable Fuels for Sustainable Mobility

Pravesh Chandra Shukla, Giacomo Belgiorno, Gabriele Di Blasio, and Avinash Kumar Agarwal

Abstract Transportation sector is facing new challenges in terms of stringent vehicle tailpipe emissions and CO_2 emission reduction, moving the sector towards decarbonisation. In this view, research in the automotive industry has been developing alternative solutions for the mid- and long-term timeframe. The main pillars are electrification, energy storage, zero-carbon renewable fuels, etc. In the transition phase towards zero tailpipe emission vehicles, improvements in state-of-the-art propulsion systems are still required. Several studies in combustion development through advanced techniques, alternative fuel applications, and after-treatment systems improvements are still facing challenges. Using alternative fuels for internal combustion engines is a sustainable way to use these devices for transportation and to reduce emissions simultaneously. This book includes a detailed review of renewable fuel solutions for sustainable mobility. It covers various renewable fuels such as hydrotreated vegetable oils, methanol, ethanol, butanol, dimethyl ether, and biodiesels. This book emphasises the role of renewable fuels as one of the solutions for sustainable transportation.

Keywords Alternative fuels · Biofuels · Fuel production · Sustainable mobility · Renewable fuels · Internal combustion engines

Mobility is one of the prime requirements of human activities in the modern world. The increasing energy demand of developed countries and the exponential growth of emergent ones have arisen concerns about pollution and CO_2 emissions and their impact on climate change. Policies around the world are defining rules to mitigate

P. C. Shukla (✉)
Department of Mechanical Engineering, Indian Institute of Technology Bhilai, Raipur, India
e-mail: pravesh@iitbhilai.ac.in

G. Belgiorno
PUNCH Torino, Turin, Italy

G. Di Blasio
Istituto di Scienze e Tecnologie per l'Energia e la Mobilità Sostenibili (STEMS), Consiglio Nazionale Delle Ricerche, Naples, Italy

A. K. Agarwal
Department of Mechanical Engineering, Indian Institute of Technology Kanpur, Kanpur, India

P. C. Shukla et al. (eds.), *Renewable Fuels for Sustainable Mobility*, Energy, Environment, and Sustainability, https://doi.org/10.1007/978-981-99-1392-3_1

their impact on the environment and human health (IEA 2022; European Green Deal n.d.). In this regard, pollutant emission regulations are becoming stricter, and tank-to-wheel emissions will be reduced to almost zero in the mid-term. Several solutions can support the transition of the transportation sector towards decarbonisation. Recent regulations move mobility towards carbon-neutral by 2050. The green electrification of vehicle propulsion systems represents a mainstream strategy, and electric vehicles are getting popularity in recent times. Although electric vehicles produce no emissions in the urban environment, these machines use electricity mostly produced using conventional fuels like coal and CNG, which ultimately release tonnes of CO_2 and other pollutants into the environment.

Moreover, mining of lithium, production of lithium batteries and recycling also possess limitations. In a more convenient and cheaper approach, researchers and manufacturers have been working on conventional propulsion system development and novel alternative fuel designs to minimise the transportation sector's environmental impact. Thus, renewable fuels, such as bio-alcohols, biogases, zero-carbon fuels and synthetic fuels, play a crucial role in facing the challenging goals to decarbonise the transport sector (Verhelst and Turner 2019; Sahu et al. 2022; Ianniello et al. 2021). The proposed book extends the scientific and technical discussion and overviews on renewable fuels for clean transportation presented in previous monographs (Blasio et al. 2022a, b; Shukla et al. 2021). This book attempts to study the application of renewable fuels for transport applications, methods for production and basic research techniques for their characterisation in internal combustion (IC) engines. The first section describes the application of renewable fuels, mostly alcohol fuels, in IC engines. The second section deals with fuel production, and finally the last section describes some optical techniques for fuel spray and combustion characterisation. The three sections are, respectively, named (I) renewable fuel applications, (II) renewable fuels production and (III) miscellaneous. A total of 12 chapters are included comprehensive of this introduction.

The first chapter entitled 'Hydrotreated Vegetable Oils for Compression Ignition Engines—the way toward a sustainable transport' deals with the application of Hydrotreated Vegetable Oils (HVO) in modern compression ignition (CI) engines. It highlights the advantages of life-cycle assessment (LCA) and well-to-wheel (WTW). Effects on the combustion process and pollutant emissions are also discussed, demonstrating as HVO is highly compatible with existing engines and fuelling systems. Proceeding with the discussion on the application of alternative fuels, Chap. 2 discusses 'DME as a Green Fuel for Transport Sector'. This chapter primarily deals with the application of DME in IC engines as an excellent option to reduce soot formations. Emission reduction potential is also discussed, demonstrating the superior fuel properties, in terms of cetane number (CN), oxygen content, etc. to improve the fuel atomisation and the combustion process.

Chapter 3 investigates the '*Combustion and Emission Characteristics of Oxygenated Alternative Fuels in Compression Ignition Engines*'. In particular, it assesses the potential of using alcohol fuels in CI engines. An overview of CI engines fuelled with oxygenated fuels (biodiesel and alcohols blends) on combustion characteristics, engine performance and exhaust emissions is presented, demonstrating their

effectiveness in reducing CO_2 and particulate emissions. A study on the short-term application of alternative fuels is conducted in Chap. 4, which deals with the '*Functional Use-based Positioning of Conventional Vehicles in conjunction with Alternate Low-Emission Fuels*' in India. The study discusses alternative fuels (natural gas, auto-gas and hydrogen) applicable to IC engines. The study demonstrates that biofuel blends are deployable for all vehicles running on conventional petrol or diesel.

In contrast, the expansion of natural gas usage is constrained by the lack of availability and accessibility beyond a few nodes. A specific application of alcohol fuel is reported in Chap. 5, which discusses the '*Strategies for Efficient Utilisation of methanol in Compression Ignition Engines*' through a review study. It discusses the potential of using methanol in CI engines to improve engine performance and simultaneously reduce emissions, along with dual-fuel technology. Another review study is presented in Chap. 6 which deals with '*The Impact of Renewable Fuels and Fuel Additives (Dodecanol) on Particulate Mass Emission for Sustainable Mobility*'. Experimental and comparative analyses are reported in this study, where dodecanol as a fuel additive is blended in diesel fuel. Results on in-cylinder pressure, hydrocarbon (HC), carbon monoxide (CO) and particulate mass (PM) emissions are presented. Chapter 7 deals with '*A bibliometric review of alcohol-diesel blend in CI engines*', assessing the role of alcohol additives on combustion and performance in CI engines, which were comprehensively reviewed.

Renewability and ease of production of various alternative fuels are promising points where overall CO_2 emission reduction in comparison to the production of conventional fuels. Therefore, Part II is included in this book which mainly focusses on the explanation of the production processes of renewable fuels. Chapter 9 belongs to the fuel production section and deals with the '*Biomass and CO_2-derived fuels through carbon-based catalysis. Recent advances and future challenges*'. The chapter describes the production of liquid transportation fuels from biomass and CO_2. The most promising carbon-based catalysts and processes are presented, which discuss the main challenges to improve the performance of various catalysts and reduce the overall production cost of the fuels. Chapter 10 discusses the '*Waste-to-Energy: Applications and perspectives on sustainable aviation fuel production*'. In particular, it focusses on sustainable waste management methods for waste-to-energy conversion technologies for bio-jet fuel production. Current conversion pathways are further analysed and discussed towards a 'greener' and more sustainable future for the aviation industry.

Most suitable alternative fuels for IC engines defer in their physicochemical fuel properties. Therefore, it is important to study the spray behaviours and other related characteristics before adapting to the commercial level. The last section presents various optical diagnostic techniques for fuel spray and combustion assessments. Chapter 11 explains the '*Feasibility Study of Laser Plasma-Assisted Stratified Combustion and Spray Investigations in a Constant Volume Chamber*'. This chapter explains techniques of spray analysis for gasoline direct injection (GDI) applications such as the Schlieren imaging technique, laser-induced fluorescence, Mie scattering, and phase Doppler interferometry. Fundamentals of laser ignition and associated challenges for the stratified mode of GDI engine operation were also covered. Other

optical techniques are also discussed in Chap. 12, titled 'Understanding Combustion in CI Engines for Adoption of Renewable Fuels'. It deals with a detailed explanation of diesel combustion through flame visualisation using various optical diagnostic techniques in constant-volume combustion chambers.

To summarise, the various sections and chapters of the content are organised in three sections: (I) Renewable Fuel Applications, (II) Renewable Fuels Production and (III) Miscellaneous which are listed below:

1. Introduction to Renewables Fuels for Sustainable Mobility.
2. Hydrotreated Vegetable Oils for Compression Ignition Engines—the way toward a sustainable transport.
3. DME as a Green Fuel for Transport Sector.
4. Combustion and Emission Characteristics of Oxygenated Alternative Fuels in Compression Ignition Engines.
5. Functional Use-based Positioning of Conventional Vehicles in conjunction with Alternate Low-Emission Fuels.
6. Strategies for Efficient Utilisation of methanol in Compression Ignition Engines.
7. The Impact of Renewable Fuels and Fuel Additives (Dodecanol) on Particulate Mass Emission for Sustainable Mobility.
8. A bibliometric review of alcohol–diesel blend in CI engines.
9. Biomass and CO_2-derived fuels through carbon-based catalysis. Recent advances and future challenges.
10. Waste-to-Energy: Applications and perspectives on sustainable aviation fuel production.
11. Feasibility Study of Laser Plasma-Assisted Stratified Combustion and Spray Investigations in a Constant Volume Chamber.
12. Understanding Combustion in CI Engines for Adoption of Renewable Fuels.

References

Di Blasio G, Agarwal AK, Belgiorno, G., Shukla, P.C. (2022a). Introduction to Application of Clean Fuels in Combustion Engines. In: Di Blasio G, Agarwal AK, Belgiorno G, Shukla PC (eds) Application of clean fuels in combustion engines. Energy, environment, and sustainability. Springer, Singapore. https://doi.org/10.1007/978-981-16-8751-8_1

Di Blasio G, Agarwal AK, Belgiorno G, Shukla PC (2022b) Introduction to clean fuels for mobility. In: Di Blasio G, Agarwal AK, Belgiorno G, Shukla PC (eds) Clean fuels for mobility. energy, environment, and sustainability. Springer, Singapore. https://doi.org/10.1007/978-981-16-8747-1_1

European Green Deal (n.d.). https://ec.europa.eu/clima/eu-action/european-green-deal_en. Accessed 11 Nov 2022

Ianniello R, Belgiorno G, Di Luca G, Beatrice C, Di Blasio G (2021) Ethanol in dual-fuel and blend fueling modes for advanced combustion in compression ignition engines. In: Shukla PC, Belgiorno G, Di Blasio G, Agarwal AK (eds) Alcohol as an alternative fuel for internal combustion engines. Energy, environment, and sustainability. Springer, Singapore. https://doi.org/10.1007/978-981-16-0931-2_2

IEA. Transport sector CO_2 emissions by mode in the Sustainable Development Scenario, 2000–2030, IEA, Paris, https://www.iea.org/data-and-statistics/charts/transport-sector-co2-emissions-by-mode-in-the-sustainable-development-scenario-2000-2030. Accessed 11 Nov 2022

Sahu TK, Shukla PC, Belgiorno G, Maurya RK (2022) Alcohols as alternative fuels in compression ignition engines for sustainable transportation: a review. Energy Sour Part A: Recov Utiliz Environ Effects 44(4):8736–8759. https://doi.org/10.1080/15567036.2022.2124326

Shukla PC, Belgiorno G, Di Blasio G, Agarwal AK (2021) Introduction to alcohol as an alternative fuel for internal combustion engines. In: Shukla PC, Belgiorno G, Di Blasio G, Agarwal AK (eds) Alcohol as an alternative fuel for internal combustion engines. Energy, environment, and sustainability. Springer, Singapore. https://doi.org/10.1007/978-981-16-0931-2_1

Verhelst S, Turner JW, Sileghem L, Vancoillie J (2019) Methanol as a fuel for internal combustion engines. Progress Energy Combust Sci 70:43–88. ISSN: 0360-1285. https://doi.org/10.1016/j.pecs.2018.10.001