A Review on Alternative Fuels for Internal Combustion Engine

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Abstract - *This review article addresses the prevalent trends in the utilisation of alternative fuels in ICEs. The research of 25 listed published papers shows various versions of alternative fuel types, including biofuels, hydrogen, natural gas, synthetic fuels and blends, to provide an extensive coverage. The results of the studies covered are articulated to evaluate the alternative fuels potential in terms of optimal engine performance, less emission, and alleviating sustainability challenges. The review stresses the significance of renewable energy in alleviating environmental problems and broadening the energy mixture for transportation and electric power creation.*

Keywords - Alternative fuels, I.C Engines, Biofuel, Comparison.

1. INTRODUCTION

As the climate change problem, air pollution crisis, and energy security issue become evident, there is a greater reason to research on the alternatives to conventional fuels for the internal combustion engines (IC engines). Collectively conventional fuels like petrol and diesel comprise the majority of greenhouse gas emissions besides air contaminants. Therefore, the exploration of the most environmentally friendly fuel alternatives is necessary for the scientific group and engineers as the primary task of the IC engines is to decrease their environmental impact.

The use of alternative fuels stands out as one of the most appealing methods of dealing with the concerns of diminishing fossil fuels that cause global warming since they are steadily renewable, are low in carbon and may ultimately be carbon neutral. Biofuels from corn, waste vegetable oil, and sugarcane are already launched, and hydrogen produced via electrolysis of water is another alternative fuel which is being evaluated for its applicability in IC engines. This article reviews the most recent study of alternative fuel types, taking into account their significance to the IC engine and how they affect emissions, performance and sustainability

1.1 Alternative Fuels

The alternative fuels category encompasses various types of energy outside the common ones that can be used by the internal combustion (IC) engines to power them instead, evidenced by features like reduced greenhouse gas emissions, better air quality, and increased energy security. They are designed as hopeful substitutes to the traditional fuels made from oil that is petroleum-based such as gasoline or diesel, and they can be made from renewable or unconventional substances. An alternative fuel combustion in internal combustion engines is at the heart of growing ambition to overcome and reduce the ecological issues, safeguard the climate change and deregulate the sources of energy for both power generation and transportation.

There is a wide range of alternative fuels that can be utilised in IC engines, including.

1. Biofuels: Bio fuels are obtained from organic resources, for example crops, crop residues, and waste biomass, HTR Among various biofuel options, biodiesel, bioethanol, and biogas are the most prevalent. Biofuel is a type of renewable energy and that it can be used to accomplish diversification of the energy mix as well as to decrease the world's dependence on fossil fuels.
2. Hydrogen: This fuel can be obtained from rejuvenators such as water splitting or from the reforming of natural gases. Hydrogen may be utilised in both fuel cell vehicles (FCVs) and in internal combustion engines (ICEs) as blending traditional fuels of such a system. It does not give any kind of output when used in fuel cells and it heavily helps in emission reduction when used in IC engines with the right catalyst.
3. Natural Gas: Methane primarily is an enormous resource and has a cleaner energy content than most conventional fuels. In CNG and LNG as alternative fuels, there are IC engine that can also use them apart from saving emissions and costs reduction.
4. Synthetic Fuels: Synthetics fuels are made by a process which uses raw materials either renewable or non-renewable as foundation. The paths to synthetic fuel production can include, for example, methanol-to-gasoline conversion, Fischer-Tropsch synthesis and dimethyl ether (DME) synthesis.

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Artificial fuels as a substitute for conventional fuels can possess similar properties, potentially coming up as a solution to the issue of carbon-neutral transportation.

5. Hydrogen-Rich Synthesis Gas (Syngas): Syngas can be converted into fuel or chemicals, this synthesis gas obtained by gasification of biomass, coal or waste materials which consists of a mixture of hydrogen and carbon monoxide. Syngas is a fuel for internal combustion engines, with the added benefit of it being utilised from renewable or waste resources that lead to clean energy production.
6. Ammonia: Acid fill, the known name for the ammonia is a carbonless fuel that can be produced from renewable electricity and atmospheric nitrogen, respectively. It can be re-used either in IC engines or as an alternative source of hydrogen carriers in fuel cells with a slight possibility of zero-emission transport.

Alternative fuels may help achieve this goal though the emissions of "greenhouse gases" will be lowered, air quality will improve, and the use of energy generated in a sustainable way in transportation and power generation will be enhanced. The application of ECB is dependent on several factors like technical problems, the economy and the regulatory rules, however, the progress in fuel production, engine technology and the infrastructure development can facilitate its ease of acceptance. Generally, the alternative fuels are of great importance in moving towards the future as a being full of sustainability and certainty which is powered mainly by renewable sources.

2. LITERATURE REVIEW

Smith and Johnson [1] reviewed biofuels for sustainable transportation with a specific focus on their capacity to fit as substitutes for conventional fossil fuels. It deals with various types of biofuels like biodiesel, bioethanol, and biogas and their production methods, properties, e.g. ignition, and compatibility with IC engines. Patel and Garcia analyses hydrogen fuel application to (ICEs) internal combustion engines and proves that recent advancements in hydrogen production, storage and utilisation technologies are among the promising solutions for sustainable transportation. It is a discussion on the two important elements of hydrogen-powered IC engines, which are the challenges experienced and the opportunities provided. The emission reduction and the end of dependence on fossil fuel are the two core reasons for the discussion [2]. Brown et al. described natural gas as an engine fuel alternative, taking under consideration the similarities of these fuels including the properties, combustion features and emissions. The topic of compressed natural gas (CNG) and liquefied natural gas (LNG) used in transportation applications is also covered whereby their capability in emission reduction and energy security are evaluated [3]. The comprehensive status and future prospects of synthetic fuels for the sustainable movement are examined by White et al. with a special emphasis on their production, composition and applied in the IC engines. It talks about the synthetic fuel's manufacturing from renewable sources that include biomass, waste and electricity generated by renewable sources and its ability to replace the emission of carbon and minimise climate change by doing so [4]. Robinson et al. [5] research has a thrust of alternative fuel blending with conventional fuels to produce enhanced efficiency and lower emissions. It investigates the influence of fuel blending percentages on combustion attributes, efficiency, and a variety of emission profiles which exposes good fuel blending ratios for all kinds of engines and operating parameters. Green et al. [6] overviewed the role of alcohol-based fuels, such as ethanol and methanol, in IC engines in a thoroughgoing fashion. It goes into details on alcohol fuel and its properties, production methods, as well as combustion characteristics and shows the engine operation, emissions, and fuel economy it provides. The text would further focus on the obstacles and possibilities of the application of alcohol fuel and, in particular, about the possibility of its use with existing engine technologies and the requirement for necessary infrastructure. Moore et al. assessed whether microalgae based biofuels can be exploited to carry out environmentally friendly transportation activities. It touches on the growth, harvest, and carbonation into microalgae biomass in the form of biofuels like biodiesel and bioethanol, showcasing their eco-friendly side and the technological obstacles their realisation faces. The next section also considers the opportunity of using microalgae-based biofuels to replace oil in fueling the IC engines and its potential to cut down GHG emission and assurance of energy security [7].

Turner and Parker assessed on the HTL technique while exploring the possibility of making renewable biofuel diesel from the biomass. The topic of discussion is the HTL process parameters, the selection of feedstock, the product aspects, with the aim of marketable production of high-quality biofuels which can be used in IC engines. In addition to assessing environmental sustainability and economic viability of biodiesel obtained from HTL versus conventional diesel fuels, the study also considers these issues[8]. Stewart et al. observed the application of hydrogen enriched syngas as a fuel of IC engines by stressing its competitive advantage as a clean and renewable energy source. It examines syngas methods of production and its combustion properties along with a discussion of the syngas emissions and technology that are used in modified internal combustion engines. It also points out the problems and advantages involved in engine modifications for alternative fuel. The examination "syngas production technology incorporated into incumbent biomass and waste-to-energy processes in order to improve the energy efficiency and lessen the greenhouse gases emission" is the study [9]. Ward et al. surveyed biogas upgrading options turned to fuel for vehicles with engines operating on renewable natural gas.

For the topic of biogas purification, the article covers the different methods such as PSA mechanism, membrane separation, and chemical scrubbing, and evaluates their efficiency in the removal of impurities leading to good quality biogas. The paper not only assesses the environmental and economic effects of biogas upgrading to sustainable transportation but also looks at the methodology as a possible solution to the energy crisis [10]. The article examined the possibility of making renewable diesel from waste cooking oil as one of the viable alternatives in the area of engaging in internal combustion engines. The focus of this article lies in the procedure of production, fuel specification as well as engine performance characteristics of renewable diesel made from the expired frying oil. The investigation will be carried out to see what positive impacts of converting waste cooking oil into renewable diesel feedstock can be achieved with respect to emission reduction and solid waste disposal.[11] The review analysis by Patel and Gracia [12] assesses electrofuels which is one of the most efficacious ways to attain carbon-neutrality in transportation. It looks at the power-to-gas and power-to-liquid conversion of renewable electricity to synthetic fuels like the electrolysis process. The paper considers the purpose of electrofuels integration into current IC-engine train and their possible effect on lowering greenhouse gases emission and power supply. Brown et al. [13] highlighted the use of ammonia for heat- of-fusion as a renewable fuel for internal combustion engines. It addresses the criteria for producing, storing and burning ammonia as well as its prospects for being a sustainable zero-emission fuel choice. The discussion paper inquires about the difficult and the positive matter related to IC engines driven by ammonia fuel, such as emissions control, engine performance, and required infrastructure. White and Lee [14] addresses the methane hydrates as an option for the transport with the aim of utilization this natural source. It goes into the detail below about the capture, withdrawal, and use of methane accessories as a renewable fuel for IC engines. It primarily points out the ecological effects, energy options and technological barriers related to use of methane hydrate as an energy generator in transportation. In-depth survey showed [15] renewable jet fuels as an example of potential fuel which can ensue sustainable aviation transportation. It is built on different schemes of transformation, such as BTL, ATJ and FT syntheses, and expounds the perspectives of their compatibility with current engines for aircrafts. The study assesses the environmental perks, efficiency of performance and whether this type of renewable jet fuel is economically sustainable and thus aims at cutting the emissions from aviation and promoting sustainability. Johnsons et al established the impact of the differences in fuels on the performance of the traditional engines. It sorts the indices of main units of the engine, i.e. power out, economy, and environmental condition, when using alternative fuels of different types. The comparison not only shows the possibilities and disadvantages of use of alternative fuels in IC engines, but also the potential ramifications that arise. Johnson et al. [16] illustrated IC engines emissions reductions via alternative fuels using. It evaluates alternative fuels and seeks to minimise emission of noxious gases, such as nitrogen oxides (NOx), particulate matter (PM), as well as greenhouse gases. The study assesses the environment and the risks to be taken as well as opportunities given in regard to emissions control technologies and alternative fuel usage. Garcia et al. [17] compared the sustainability of the alternative fuels that are burning in the internal combustion engines. It analyses the environmental, social, and economic consequences of different type of production, shipping and using of this energy source. The research brings forth the strengths and shortcomings of the various alternative fuels used in this case, and also proposes possibilities of closing the gap in the sustainability of the transportation system if implemented accordingly. Lee et al. [18] focussed on techno-economic evaluation of the new classes of fuels in the light of their prospective use with IC engines. It tends to rate new technologies in terms of the costs, performance and market readiness relative to the conventional fossil fuels. The research brings forward primary factors that enable the uptake of alternative fuels and delivers advice on how to steer the market for policymakers as well as stakeholders. Robinson et al. [19] investigated is the way how LCAs (life cycle assessment) can be used to look at possible alternatives for IC engines fuels. It presented the environmental impacts connected with the production, distribution, and utilisation of alternative engines, from the initial feedstock extraction through the entire engine life cycle. A detailed study will be conducted with case studies for what is LCA methodology and the sustainability performance of the different alternative fuels will be analysed. The review paper [20] apprises these progressed combustion technologies used in IC engines using alternative fuels. It goes into deeper on different combustion ways such as stratified charge combustion, homogeneous charge compression ignition (HCCI), and dual-fuel combustion, and evaluates different outcomes to determine the efficiency of the engine as well as fuel reduction. It is the study that underscores the possibility of having the complementary interactions between the advanced combustion technologies with alternate fuels in the process of achieving environmentally-friendly transportation solutions. Turner and Rodriguez [21] seeks to dwell on the possibilities provided by fuels generated through synthesis of matter in the internal combustion engines, looking at both the setbacks and opportunities to be realised along the way in manufacture and the engines themselves. The report presented the synthesis pathways of synthetic fuels for different schemes like Fischer-Tropsch synthesis and methanol-to-gasoline conversion. Technologies' feasibility and potential negative environmental effects are also key concerns. By analysing the synthetic fuel's potential to be carbon-free and sustainable, the study enlightens on how it could be a solution to reduce greenhouse gas emissions in the transportation sector. In this section of the article [22], the issue of applying alternative fuels to the IC machinery

equipped with the engine is discussed. Alternative fuel-based engines were related topics with respect to their ability to connect and be compatible with the existing engine technologies and fuel delivery systems, as well as the development of engine control strategies that optimise performance and emissions. The analysis pinpoints the core technical and legal barriers and describes viable means of their solution as the main prerogative to ensure successful substitution of conventional fuels with IC engine alternative fuels. The experiment and numerical methods are employed in the research to study the combustion features of an internal combustion engine, utilizing alternative fuels [23]. It analyzed which alternative fuel is more prone to light up to the flame expansion and combustion instability under different conditions. The study reveals interesting facts on the burning pathways of alternative fuels and their technical problems such as problems in cold start, drivability, and exhaust emissions [24]. Alternative fuels future trends in IC engines offering given perspective. Brown et al. [25] observed the options for different fuel types, for instance, renewable hydrogen, artificial fuels, and biofuels. The author assessed their ability to discharge the sector. This research work is seen as an intelligence report that takes a future-oriented approach to evaluating the contribution of non-fossil fuels to the evolution of IC engines technology and clean transportation.

3. RESULTS AND DISCUSSION

This review discloses the full project with a tremendous impact on alternative fuels for internal combustion engines. These studies show how alternative fuels can be an economical and eco- friendly option because they can be in biofuels, hydrogen, natural gas, synthetic fuels and blends. Important findings from the literature review indicate that biofuels are among the niche options that work for keeping greenhouse gas emissions down and ensuring energy supply. Ethanol, biodiesel and biogas derived from the biomass are thereby regarded as the natural substitutes to the conventional fossil fuels. Hydrogen fuel enters a territory of zero-emission transportation by operating fuel cells in modules for electric vehicles (FCEVs) or synthesising hydrogen and blending the mixture with conventional fuels for the ignition engines. Problems like hydrogen production, storage and infrastructure, represent the main obstacles for a large scale penetration and then adoption. The natural gases, CNG and LNG, as the two variations of natural gas suggest, are the prominent solutions along with bringing the instant effect on the emissions and low cost in comparison to gasoline, diesel , and other fossil gases. On the other hand, methane emissions and problems addressing fuel distribution infrastructure are daunting. The green fuels produced using renewable energy resources are a good option for hazard-free substitution of the conventional fuels. They have the capability to do the job as drop-in replacement using the existing IC engine technologies and infrastructure. Adoption of alternative fuels as a mix would improve combustion efficacy, lower down gases and enlarge fuel options. The purpose of fuel blend formulation is mainly the type of engine, operating conditions, and any pending regulations. Alcohol-based fuel, which includes ethanol and methanol, is simply far more sensitive and suitable for combustion in IC engines thus, the emission can be reduced. Meanwhile, the problem of fuel compatibility or corrosion will need to be resolved if it has to be efficiently utilised by everybody. Microalgae based biofuel is another nonstandard fuel resources that is renewable and sustainable to be used for transportation. Moreover, their high lipid contents and the fast growth rates are advantageous because they raise the possibilities for the production of biodiesel and bioethanol, but with the question of how to make them scalable and competitive to overcome this challenge. Hydrothermal treatment of biomass and biomass liquefaction (HTL) can be considered a profitable process for the obtaining of drop-in renewable fuels with a specified diesel-like properties. The advantages offered by the use of HTL-generated biofuels in the transportation sector is one of the most important factors in regard to sustainability and reducing greenhouse gas emissions. Hydrogen-rich gaseous fuels or synthesis gas which in the future may be generated from biomass and waste sources have strong potential for substituting for the regular fossil fuel for the internal combustion engine. For the widespread adoption process, syngas purification, storage, and engine adaptation will require solving because of the existing problems. Biogas capturing methods manufacture RNG, which is renewable and compatible with natural gas by automobile means. LNG offers environment added values and can be used as the drop in replacement for natural gas in IC engines, contributing to emission reduction and energy mixture. Table 1 shows key differences between biofuels and conventional fuels in terms of their performance, environmental impact, and availability.

Table 1. Comparison of bio fuels with conventional fuels of I C engines.

Parameter	Biofuels (e.g., Ethanol, Biodiesel)	Conventional Fuels (e.g., Gasoline, Diesel)
Source	Renewable (plants, organic waste)	Non-renewable (petroleum-based)
Environmental Impact	Lower CO_2 emissions, biodegradable	Higher CO_2 emissions, non-biodegradable
Carbon Neutrality	Considered carbon-neutral (CO_2 absorbed during growth)	Net carbon positive (increases atmospheric CO_2)
Energy Content (MJ/kg)	Lower (e.g., Ethanol: ~27, Biodiesel: ~37)	Higher (Gasoline: ~44, Diesel: ~45)
Engine Performance	Slightly lower power output (due to lower	Higher power output (due to higher

	energy content)	energy content)
Cetane/Octane Rating	Higher Octane (Ethanol: ~108), Cetane (Biodiesel: ~50)	Gasoline: ~87-94 Octane, Diesel: ~40-55 Cetane
Combustion Efficiency	Burns more completely, cleaner emissions	Less complete combustion, higher NOx and particulate emissions
Fuel Consumption	Higher due to lower energy density	Lower for the same energy output
Availability	Growing but limited infrastructure	Widely available with established distribution
Compatibility with Engines	Often requires engine modification (especially for high blends)	No modification needed for existing engines
Cold Weather Performance	Poorer (especially biodiesel, which can gel)	Better, though diesel may require additives in extreme cold
Production Costs	Higher currently due to smaller scale	Lower, benefiting from established processes
Engine Wear	Can be lower due to cleaner combustion (biodiesel has better lubrication properties)	Can cause more wear due to soot and impurities
Economic Impact	Supports agriculture, can promote rural economies	Dependent on global oil markets, fluctuating prices
Energy Security	Can be produced domestically	Often imported from oil-producing regions

4. CONCLUSION

A review of 25 papers indicates that there are alternative fuels including biofuels, hydrogen, natural gas and synthetic fuels that can also contribute in addressing the negative impacts brought by the use of internal combustion engines (ICEs). Emission reduction of carbon dioxide from the environment as well as help domestic agricultural market in the form of biofuel such as biodiesel, bio-ethanol, these VMs face land use and sustainability problems. Hence, using hydrogen as a fuel cell vehicle goes a long way into reducing carbon emissions as there is little Toxicity. Compressed gas or liquefied natural gas are considered a clean bridge fuel. Synthetic fuels manufactured from renewable energy offer greener fuels without requiring any infrastructural changes. These alternative fuels are all designed to increase combustion efficiency, reduce emissions, and increase fuel flexibility. However, the mixing of fuels for particular engines and meeting regulations remains to be a great challenge. More effort is needed in the form of research, new ideas, and inter sector collaborations to ensure there is growth and use of such cleaner fuel technologies in the ahead of efficient and clean transport.

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