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A Review on Alternative Fuels Use in Internal Combustion Engines

Ravindra S. Deshpande[1], Prashant Patil[2], Nitin Kardekar[3], Shrinivas Rathod[4], Uday Aswalekar[5], Satish M. Silaskar[6] and S. S. Thipse[7]

[1]*Department of Mechanical Engineering, Sinhgad College of Engineering (SCOE), Vadgaon (Bk) - 411041, Pune, Maharashtra, India; ravindra.deshpande8888@gmail.com*
[2]*Abhinav Education Society's College of Engineering and Technology, Pune - 411046, Maharashtra, India*
[3]*JSPM Narhe Technical Campus, Pune - 411041, Maharashtra, India*
[4]*Thakur College of Engineering and Technology, Mumbai - 400101, Maharashtra, India*
[5]*Vidhyvardhi College of Engineering and Technology, Mumbai - 401202, Maharashtra, India*
[6]*Horizon Institute of Technology and Management, Thane, Mumbai - 400615, Maharashtra, India*
[7]*Department of Powertrain Engineering, ARAI, Pune - 411038, Maharashtra, India*

Abstract

The worldwide issues include rising fuel prices, air pollution, and global warming. As mineral fuels deplete, alternative fuels become increasingly significant in internal combustion engines. This article discusses liter-ature analysis to demonstrate the different types of renewable energy used worldwide. Alternative fuels can replace fossil fuels if their availability is limited by worldwide geopolitical issues. Its main objective is to review and identify the various types of alternative fuels which can be used for internal combustion en-gines to reduce emissions of CO_2 *into the atmosphere. Alcohols, LPG, biodiesel, natural gas, DME, fuel cells, hydrogen, and electricity are some alternative energy sources. Alternative fuels for both CI and SI en-gines are becoming more popular due to socioeconomic and environmental reasons. It involves transition-ing society from its dependence on petroleum and increasing concerns about sustainability. Natural gas, alcohol, hydrogen, fuel cells, and electricity are some alternative fuels that are getting much attention. These alternative fuels can minimize harmful emissions as well as operating costs.*

Keywords: *Alternative Fuels, Alcohols, Biodiesel, Hydrogen, LPG, Natural Gas*

1.0 Introduction

Research aims to decrease petroleum usage and minimize the amount of hazardous gases in the emissions that have been boosted by the world's growing energy demand, increasing environmental issues, and higher energy costs. Burning fossil fuel produces an adverse effect on the environment, particularly when it comes to transportation, which has made it imperative to address these issues swiftly. Global priorities have focused on protecting the environment and reducing emissions from fossil fuels[1]. Alternative fuels were extensively used in automobiles in many countries due to their government support, economic benefits, and concern for the environment and energy security as well as reducing harmful emissions from automobiles and operating costs[2]. About 25% of the world's power and 17% of its GHG emissions today come from IC engines that run on fossil fuels and also produce

**Author for correspondence*

other major pollutants like PM, CO_2, CO, and NO_x all of which have negative impacts on the quality of the air in urban areas[3]. Alternative fuels give multiple benefits over traditional fossil fuels in India. Some of the main benefits of alternative fuels are: (1) Lower emissions of greenhouse gases: Electricity, hydrogen, and biofuels are examples of alternative fuels that can help in lowering greenhouse gas emissions that cause global warming. Using these fuels can help prevent climate change and make a cleaner environment. (2) Increased air quality: When compared to traditional fossil fuels, alternative fuels generate lower hazardous emissions. This may result in less smog, better air quality, and a decrease in contaminants that are harmful to human health. (3) Less dependence on oil: The use of alternative fuels can decrease dependence on fossil fuels such as oil, which are limited resources with negative effects on the environment and global affairs. Countries can boost energy independence and reduce their need for oil imports by shifting to substitute fuels. (4) Economic growth and job creation: The development and implementation of alternative fuels have made it possible to generate new job prospects in sectors including biofuel manufacturing, renewable energy, and electric car manufacturing. This can promote innovation in the energy sector and help in economic growth. (5) Energy security: Alternative fuels can improve energy security by diversifying the sources of energy used for transportation and other purposes. Minimizing dependence on fossil fuels and imported oil can help governments reduce their vulnerability to supply shortages and price variations. (6) Renewable energy and sustainability: Many alternative fuels are made from sustainable resources like water, solar energy, biomass, and wind. By reducing dependency on finite fossil fuel reserves, using these resources helps to sustainability. (7) Diversification of energy sources: Diversifying the energy sources used for electricity, heating, and transportation is made possible by alternative fuels. Diversification has the potential to improve energy resilience and promote innovation in the energy sector. (8) Technological development: The use of alternative fuels promotes innovation in technologies like biofuel production processes, fuel cells, renewable energy systems, and battery technology. This may encourage the advancement of sustainable energy sources and clean energy technologies. Alternative fuels are an important part of the transition to a more sustainable energy system because they provide several advantages that can help address problems which is related to the economy, environment, and energy security.

2.0 Alternative Fuels for IC Engines

2.1 Hydrogen

It is widely recognized that hydrogen energy will enable us to go forward without using fossil fuels for transportation. Hydrogen (H_2) is the only fuel that produces no carbon, CO, or CO_2, resulting in low NOx emissions and high efficiency. The only IC engines that will be able to fulfill future EU standards are those that run on hydrogen. Hydrogen has a high combustion efficiency. Because of its properties for use in IC engines, hydrogen (H_2) is the potential fuel of most interest in the energy transition towards sustainable mobility, even though other fuels may also be utilized.

The article gives a relation of hydrogen to other common fuels, like ammonia and biofuels, that are utilized in regular spark-ignition engines *i.e.* petrol, methane, and diesel, or the transition to vehicles with

Table 1. Main properties of various fuels[4]

Properties	Diesel	Gasoline	Hydrogen	Ammonia	Methane
Autoignition Temp (^{0}C)	180-320	260-460	585	651	540-630
Flame velocity (cm/s)	30	37-43	265-325	70	38
Lower heating value (MJ/kg)	42.5	44.0	120	22.5	50.0

zero atmospheric emissions, like CO_2. Ammonia is the substance with the highest autoignition temperature, as Table 1 shows, making it more difficult to ignite[4]. Currently, the aerospace industry is the major user of hydrogen as rocket fuel. Hydrogen (H_2) is another fuel that can be used in fuel cells. Despite being utilized in several vehicle demonstration projects, hydrogen fuel's comparatively high price has prevented it from being adopted as a common alternative fuel. To reduce cold start emissions, dual fuel engines have been employing petrol at full load and hydrogen during startup and low load[5]. When hydrogen is replaced by hydrocarbon fuels like natural gas (NG) diesel, and petrol in internal combustion engines, Thermal Efficiency (THE) can be raised while carbon emissions are decreased. The advantage of using hydrogen for transportation is that it reduces our need for fossil fuels and increases our reliance on renewable energy sources. One of the main drawbacks of fossil fuels is their toxic tailpipe emissions. Hydrogen has 3 times the heating value of Gasoline (G) in fuel cells and IC engines. In comparison to diesel engines, SI engines are more suited for using hydrogen due to their distinct characteristics. Additionally, hydrogen works better in SI engines than in diesel engines due to its greater combustion temperature of around 858 K[6]. While hydrogen is useful in ICEs, its main benefit comes from its usage as an energy carrier in fuel cells, which only produce water and electricity. Fuel cell hybrid vehicles are a better option than completely electric cars in terms of range as well as refueling periods since hydrogen has a higher energy density than batteries. This is the main benefit of hydrogen in transportation[7].

2.2 Alcohols

2.2.1 Ethanol

The most basic type of alcohol is ethanol, sometimes referred to as "ethyl alcohol," which is typically produced

Table 2. Physical and chemical properties of both ethanol and methanol fuel[10]

Properties	Ethanol	Methanol
Research octane rating (RON)	111	114
Motor octane rating (MON)	94	96
Density (kg/m^3)	789	791
Stoichiometric ratio (kmol of air/kgof fuel) (kg of air/kg of fuel)	0.309	0.223
Hydrogen content (% mass)	34.7	50
Heating value (MJ/kg)	27.0	19.5
The heating value of the stoichiometric air/fuel mixture (kJ/Nm^3)	3850	3860
Boiling point (°C)	78	65
Autoignition point (°C)	450	500
Heat of vaporization (kJ/kg)	879	1101
Vapor pressure (kPa)	21	52
Oxygen content (% mass)	34.7	50
Carbon content (% mass)	789	791

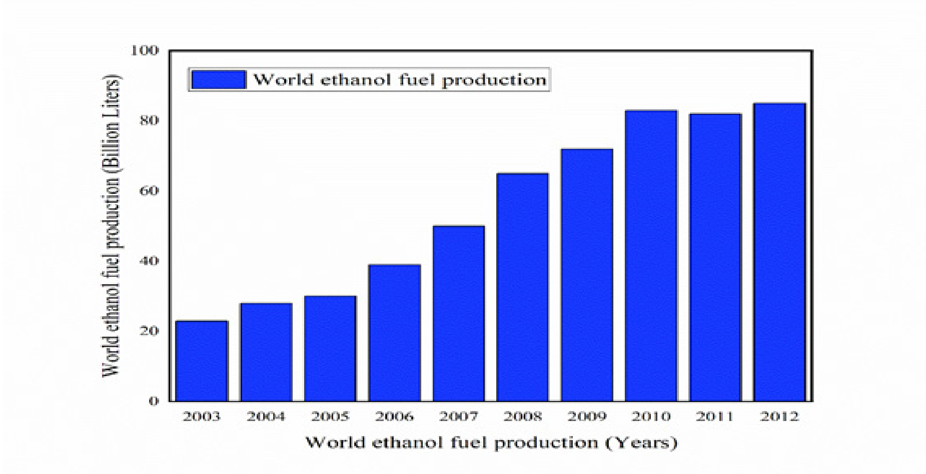

Figure 2. World ethanol fuel production[12].

by fermenting biological sources. Nowadays, a significant amount of ethanol is needed for both medical purposes and the production of alcoholic beverages. Gasoline has a Heating Value (HV) of 44 MJ/kg, while ethanol fuel has approximately 27 MJ/kg. This means that larger storage tanks need to be formed. An engine running on an ethanol-gasoline blend shows satisfactory performance and efficiency[8]. Due to its oxygen-containing properties, ethanol is a sustainable energy source that can lower combustion chamber emissions. Because it contains less carbon than regular gasoline, ethanol significantly decreases emissions when used in combustion engines operating at full load, based on a study[9].

Less petroleum use and the quantity of particulate matter and carbon monoxide released by city buses are the main reasons for the use of ethanol as well as diesel[10]. The increased CO_2 production is caused by a higher latent Heat of Vaporization (HOV), of ethanol based on study. Ethanol (E) with a higher oxygen content is added, the CO_2 level will also drop[11].

Production of Ethanol (E) as a fuel has increased significantly during the last ten years worldwide (Figure 1). The total quantity of ethanol fuel manufactured in 2012 was 85.985 billion L. By 88.4% of the world's total Ethanol (E) production, USA is the leading globally producer. Even though many countries are actively working to reduce their reliance on improving air quality, increasing rural economies, and oil imports ethanol fuel production has increased significantly. Fuel blends of ethanol and gasoline are utilized in many regions of the world, including Canada, Thailand, Brazil, and the European Union[12].

2.2.2 Use of Ethanol Fuel

- **Cost Effective** - It rational sense for these developing economies to concentrate on producing ethanol fuel in order to decrease their dependence on fossil fuels and thus save money.
- **Environmentally Friendly** - There are several benefits that ethanol gives over gasoline and diesel, the most important being that it is not harmful to the environment. Ethanol leads to significantly fewer pollution releases into the environment when used as vehicle fuel. Gasoline and ethanol are often mixed to speed up the fuel's conversion process.
- **Abatement of Climate Change** - Ethanol fuel burns to merely produce carbon dioxide and water as byproducts. The environment is not substantially harmed by carbon dioxide emissions.
- **Availability** - Ethanol is a type of biofuel that almost everyone may obtain with little effort.
- Alternative for Fossil Fuels - Ethanol plays a role in lowering greenhouse gas emissions and dependence on imported oil.
- **Unlocks the Potential of the Agricultural Industry** - The nation's economy will improve as a result of the ethanol industry's dependency on agricultural goods, which will drive many people into the neglected agricultural sector[13].

2.2.3 Methanol

Chemically implying methanol is the most basic form of alcohol, each molecule has one carbon atom. Another name for methanol is "wood alcohol". It's a tasteless, colorless, and toxic liquid. Compared to petroleum-based fuels, it gives a lot of benefits. The first is cheap and can be made in a variety of processes, one of which uses synthesis gas. The second property is minimal emissions. Methanol's lower Boiling Point (BP) allows for faster fuel evaporation, which improves performance and reduces HC pollutants. Furthermore, in SI engines, the high oxygen concentration and simple chemical structure of methanol might result in less emissions and increased combustion[14]. Methanol makes for a better engine fuel than petrol. There are no emission issues and the engine has improved thermal efficiency values. Higher compression engines perform best in methanol fuel because of its substantial octane number of 106. The consumers, the environment, and the economy all gain from methanol. When evaluated based on mass units, methanol has less energy than petrol. For Methanol (M) and C_8H_{18}, the Lower Heating Values (LHV) are about 19.9 MJ/kg and 44.4 MJ/kg of the liquid fuel. Methanol fuel has several advantages over petrol, such as reduced flammability, high performance, and low exhaust emissions. Further carbon-based feedstocks that can be used to produce methanol include coal, biomass, and Natural Gas (NG), which can lessen reliance on petroleum imports[15]. Methanol (M) is a less well-known alternative energy biomass product that has the potential to replace fossil fuels in today's world. In addition, compared to gasoline and benzene, methanol fuel has less of an adverse environmental effect[16].

2.2.4 Use of Methanol Fuel

- Less flammability constraints allow for more efficient combustion, which improves fuel efficiency and minimizes NOx, CO, and THC emissions.
- Increased octane rating results in improved resistance to knock. To achieve better thermal efficiency, the CR can also be raised.
- When compared to conventional fuels such as gasoline and diesel, methanol produces relatively low exhaust emissions. Because methanol fuel contains less carbon by mass and is a homogenous mixture, it burns cleaner (soot-free).
- Most modern cars can easily use lower methanol blends, such as M5, M10, and M15, with just minimal system adjustments.
- More volatility is observed in multi-cylinder carbureted engines, which leads to a wider range of fuel mass and air-fuel ratio during each cycle.
- This increases latent heat of vaporization, which leads to the formation of a homogeneous mixture and a drop in in-cylinder temperature. Volumetric efficiency is increased overall[17].

2.3 Biodiesel

One of the major benefits of using biodiesel as fuel is that it generates fewer emissions than CI, including PM, CO_2, CO, HC, and SO_2. Because it has a higher cetane number, biodiesel can improve the vehicle's performance. Biodiesel lowers maintenance requirements and increases engine life. Compared to CI, biodiesel has better aromatic content, flash point, sulphur concentration, and biodegradability. Because it is less hazardous, more biodegradable, and has a higher ignition point, it is safer to handle. Increased rain and cloud points cause freezing during cold weather, which initiates cold weather[18]. At all loads, palm biodiesel emits more CO_2 than diesel, with a maximum increase of 8.76%. On the other hand, with apricot seed kernel biodiesel, the opposite type of trend, with a maximum reduction of 10.88%. Because biodiesel's molecular structure contains oxygen, which improves combustion, a rise in CO_2 emissions from CI engines is predicted by theoretical studies when biodiesel is added to diesel fuel. However, the CO_2 pollutants tend to go lower because biodiesel has a lesser carbon content to hydrogen ratio[19].

2.4 Natural gas

The best way to balance engine performance and environmental impact has been studied extensively when it comes to using natural gas in IC engines. Compared to internal combustion engines, gas turbines powered by natural gas produce fewer emissions, except CO_2 which results from gas turbines higher fuel consumption as a result of their lower efficiency compared to IC engines. The usage of NG fuel for the CI engines in LNG

Table 3. Properties of Natural gas[22]

Component	v/v (%)	Component	v/v (%)
CH_4	91.72 ± 1.7	C_5H_{12}	0.03 ± 0.03
C_2H_6	5.5 ± 1.6	N_2	0.322 ± 0.3
C_3H_8	1.98 ± 0.8	CO_2	0.03 ± 0.03
C_4H_{10}	0.44 ± 0.5	Lower heating value (MJ/kg)	49.5 ± 0.2
Density (kg/m^3)	0.788	Stoichiometric A/F ratio	17.20

containers has recently been adopted by the marine industry. Compared to petroleum products, natural gas has a lesser density, less sulfur content, and almost no carbon monoxide (CO) emissions. Because of its higher efficiency, lower cost, and inherent environmental friendliness, natural gas has become the most preferred fuel[20]. It provides more sense as an alternative fuel for the automotive and transportation industries because it is already widely utilized as the primary fuel for large-scale electricity generation, and commercial as well as domestic heating. However, to make it feasible to use the gaseous form for transportation, it would be required to store it either as CNG or LNG due to its very low bulk density[21].

The properties of Natural Gas (NG) are shown in Table 3. Diesel engines with high CR can run on natural gas because of its high octane number. A spark plug or pilot diesel fuel is used to burn the homogenous mixture that is formed when natural gas is quickly pumped into the intake port or cylinder and mixed with fresh air. As a result, exhaust gas emissions decrease significantly and combustion is carried out effectively. In addition, natural gas may be used on existing vehicles without requiring significant modifications, which has considerable beneficial impacts on the environment and the economy[22].

2.5 Dimethyl Ether (DME)

DME, which is mostly derived from coal and Natural Gas (NG), is a feasible diesel replacement. It can be utilized with CI engines with minimal modifications to the engine's design. Because of this, it is often used in addition to diesel. DME is an ideal fuel for auto-ignition. In comparison to diesel, also it has lower pollutants as well as higher energy combustion efficiency. There is a trade-off between NOx and PM exhaust emissions since Sulphur content and properties of diesel fuels, but this is not an issue with DME combustion. Improved DME atomization and evaporation contribute to decreased emissions and costs[19]. Dimethyl ether has minimal viscosity, low LHV, and poor lubricating characteristics however since it burns soot-free and has the potential to have a high exhaust gas recirculation for reducing NOx pollutants, research and development of vehicles and DME-fuelled engines is necessary. Moreover, as DME is a synthetic fuel, its development and use in vehicles might help alleviate the lack of resources, particularly fossil fuels[23].

2.6 Liquefied Petroleum Gas

In addition to a small amount of butane, propylene, butylenes, and other hydrocarbons, propane makes up the majority of LPG. Because there are already processing facilities, an infrastructure of pipelines, and storage facilities to ensure its effective distribution, LPG, is a widely used alternative fuel. The engine has virtually low carbon build-up. Propane engines are known for their longer engine life compared to gasoline engines. Because LPG burns cleanly and leaves no solid waste behind, propane is a popular fuel for internal combustion engines. Its high octane rating prevents it from diluting lubricants. Owing to the reduced volumetric efficiency, an LPG engine operating at the same speed produces less torque than an air-fueled engine. Compared to a gasoline engine, brake fuel conversion efficiency is marginally higher. NOx emissions decrease with a lower combustion temperature. There is a small decrease in $CO2$ emissions and Higher HC emissions are present[10]. Upon injecting more LPG into the Intake Port (IP), the methanol blended LPG engine demonstrated cold start capability at the minimum possible atmospheric temperature. The research evaluated how atmospheric temperature affects formaldehyde, firing, and unburned-methanol pollutants of SI and M-LPG engines with electronically operated input ports[24].

2.7 Fuel cell

For a fuel cell, gaseous fuel (like hydrogen) and oxidant gas are combined electrochemically via the electrode and ion-conducting electrolytes to generate electricity. Fuel cell produces electricity by using H_2 and $O2$. About 20% of the fuel is oxygen, which is present in the air as opposed to H_2, which is difficult to carry as well as store. Due to this, readily available fuels such as hydrocarbons or alcohol are utilized[25]. They give better alternatives to traditional energy generation technologies in small-scale applications. Hydrocarbon as well as hydrogen fuels have a higher chemical energy content than typical battery materials. Fuel cells are 30 to 90 percent more efficient than conventional gasoline ICE. Hydrogen FCVs offer zero polluting emissions, which is their primary advantage. In other words, automobiles with fuel cell energy systems have minimal or limited environmental impacts because they produce simply electricity, heat, and water[26].

2.8 Electricity

Vehicles powered by battery and fuel cells can both run on electricity as a fuel. Electricity used to supply power to the vehicle is called electric fuel. The electrochemical process that takes place in a fuel cell stack when H_2 and O_2 are combined produces the energy needed to power fuel cell cars. Fuel cells generate only two byproducts when they are used to generate electricity: Heat and water. No combustion or other pollutants are produced during this process. In contrast to batteries, which store energy, fuel cell devices produce electricity by using chemical energy. Fewer emissions and parts that require repair and replacement are among their benefits. Gasoline is more expensive than electricity.

3.0 Future Scope of Alternative Fuels

Solid biomass and biodiesel are the two types of biofuels that are currently the only commercially feasible alternatives for industrial and transportation applications. To ensure sustainability, new solutions must be developed because their use is likely to increase further in the future. Furthermore, waste management can be effectively comprised of the process of manufacturing enhanced biofuels while simultaneously resolving environmental issues and improving biofuel quality.

Hydrogen provides a viable fuel option for high-temperature industrial processes and transportation applications due to its increased energy density. However, hydrogen finds numerous uses in other fields as well, indicating that there would only be a limited amount available for fuel. Ammonia has the potential to be employed as an energy carrier or storage because of its high hydrogen gravimetric density and lack of distribution problems. Additionally, methanol is the most basic alcohol has been thoroughly tested for usage in marine applications, with positive results in the form of increased engine efficiency and decreased exhaust emission.

It mainly implies to utilizing solar energy directly to run the manufacturing process or combining other technologies, including electrolysis and capture of carbon, with the VRES to give fuel synthesis feedstock in an eco-friendly way.

4.0 Conclusions

This paper presents a review of various alternative fuel solutions that could be utilized to sustainably fuel automobile engines in the future. There are some alternatives to using fossil fuels in combination with internal combustion engines to run motor cars, such as conventional vehicles, fuel cells, and battery electric cars driven by biofuels or renewable energy sources. The articles reviewed the various alternatives for fossil fuel replacements while keeping this in mind. Even though they will be driven by electricity, futuristic liquid fuels look to still be used in internal combustion engines (IC engines), but their fuel consumption, CO_2 emissions, as well as exhaust emissions will be lower than those of fossil fuels. From the most familiar biodiesel and alcohols to very

Table 4. Shows comparison of ethanol fuel blends with engine performance and emissions[27]

Reference	Engine type	Blending ratio	Operating conditions	Engine performance				Emissions			
				BFSC	BTE	BP	T	CO_2	CO	HC	NOx
1.Tekin and Saridemir, 2017[28]	64 mm stroke, 8:1 CR, 4-stroke SI engine, 64 mm bore, 45 mm stroke, 163.46 cc capacity, 196 cc displacement	E10, E20, E30 E40, E40+ E50	1500-3500 rpm, Max. horse power (HP/rpm) 6.5/3600, Max. Torque (Nm/ rpm) 13/2500, Air- cooled	E10, E20, E60, BSFC↑ E20, E30, BSFC↓	E20, E30, BTE↑ [a] At Max. *N*, BTE↓	*N*↑, BP↑	E20, T↑[a]	E↑, CO_2↑ *N*↓	E↑, CO↓, *N*↑, CO↑	E↑, HC↓	---
2. Nwufo *et al.* 2017[29]	3-cylinder, 4-stroke SI engine, 68.5 mm bore, 72 mm stroke, 25cc Fuel consumption	E0, E5, E10+E15	Varying engine torque, constant speed 2000 rpm, speed rate 5500 rpm, Power rate 29.5 KW, Water-cooled	T↑, BSFC↓	T↑, BTE↑	BP↑	---	CO_2↑ at all blends	E↑, CO↓	E↑, HC↓	NOx↓
3. Doğan *et al.* 2017[30]	4-cylinder, 4- stroke SI engine, 73.96 mm bore, 75.48 mm Stroke, 1297 cc cylinder vol	E0, E10, E20+E30	8.8:1 CR, 2000-4500 rpm, Max. Power 43KW/5000 rpm, Max. Torque 98 Nm/2500 rpm, 1-2-4-3 order, Idle speed 750 rpm, 12°BTDC-48°ABDC, 13-16 bar CP	E0, BSFC↓ 3000 rpmE30, BSFC↑ (Max. *N*)	*N*↑, BTE↓	*N*↑, BP↑	E0, Max. T↑[a]E30, T↓ (Max. *N*)	E0, CO_2↑ 3000 rpm	E0, CO↑ E30, CO↓	*N*↑, HC↓	E30, NOx↓

4. Saikrishnan *et al.* 2018[31]	Single cylinder, 4-stroke SI engine, 88 mm bore, 64 mm stroke, 8:1 CR	E10, E20, E30 + E40	8:1 CR, 1250-3750 rpm, Max. Power (KW/rpm) 9.6/3500, Max. Torque (Nm/rpm) 26.48/2500, Air cooled	E10, BSFC↑ E30, BSFC↓	---	E10, BP↓E40, BP↑	E10+ E40, T↑ E30, T↓	E10, CO_2↓ E40, CO_2↑	E10, CO↑E30, CO↓	E10, HC↑E40, HC↓	---
5. Wang *et al.* 2018[32]	TC DISI, 3.5:1 CR	E10, E20, E30,E40, E50 + E 60	Operated at knock-free load conditions, constant speed	---	↓ by 7.07 %	---	---	↑ by 21.2%	---	---	---

[a] = at engine speed 2500 rpm; + = and; ↑ = increase; ↓ = decrease; *N* = engine speed; *N*↑ = when engine speed increase; *N*↓ = when engine speed decrease; CR = compression ratio; CP = compressive pressure; PFI = port fuel ignition; SI = spark ignition; Max. = Maximum, BTDC= before top dead center, ABDC= after bottom dead center, TC DISI = turbocharged direct injection spark ignition

Table 5. Shows comparison of methanol fuel blends with engine performance and emissions[27]

Reference	Engine type	Blending ratio	Operating conditions	Engine performance				Emissions			
				BFSC	BTE	BP	T	CO_2	CO	HC	NOx
1. Yao *et al.* 2016[33]	4-cylinder, 4- stroke PFI SI engine, 78.7 mm engine, 78.7 mm bore, 69 mm stroke, 1.342 L displacement, valves	M0, M10, M20, M30, M50 + M70	9.3:1 CR, 1200-2800 rpm, in-cylinder mixture air-fuel ratio, Max. Power 63.2KW/, Max. Torque 109.8Nm/ 5200rpm, water- cooled	---	---	---	---	---	CO↓	M50, M70, HC↓	NOx↓

2. Sharudin *et al.* 2017[34]	4-cylinder, Multipoint port fuel system SI engine,1.6 L displacement, 78 mm bore, 84 mm stroke, 159 capacity, 138 kg weight	M5	10:1 CR, 1000-2500 rpm, at constant throttle 100%	BSFC↑ at1000 rpm	BTE↑ at 2500	BP↑ 3.9%	---	CO_2↑[c]	CO↓[c]	HC↓[c]	NOx↓[c]
3. Divakar *et al.* 2017[35]	Single cylinder, 4-stroke SI engine, 70 mm bore, 66.7 mm stroke, 256 cc displacement	M10, M15, M20, M25 + M30	4.5-10.5:1 CR, varying load, 28° BTDC -32° BTDC, Power 2.8 KW/ 3000 rpm water-cooled	---	M30, BTE↑[a] 30%	M30, BP↑[a]	---	CO_2↑[a]	CO↓ at all blends	M↑, HC↓	NOx↓
4. Alexandru etal. 2017[36]	Single cylinder, 4-stroke SI engine, 72 mm bore, 60 mm stroke, 244 cc displacement	M5, M10, M15,M20 + M25	9.8:1 CR, 2000-7000 rpm Max. Power 17 HP/ 7000rpm, at various loads, air-cooled	---	---	M, BP↑ *N*↑	M5, T↑ at 5000 rpm	M, CO_2↓[a]	M, CO↓[b]	M, HC↑[a]	---
5. Wani 2018[37]	Single cylinder, 4-stroke SI engine, 500 cc displaced, speed rate 6000 rpm	M0, M15, M30, M45, M60+M75	9:1 CR, 0-8000 rpm, at stoichio-metric air/ fuel ratio, at high octane rate	BSFC↑ at all blends	---	M, BP↓ atall blends	T↑ at 2000 rpm	---	CO↑ atblends	HC↑	NOx↓

[a] = at high engine load; [b] = at low engine load; [c] = at all engine speed, BTDC= before top dead center; MPPI = Multi-point port injection; + = and; ↑ = increase; ↓ = decrease; *N* = engine speed; *N*↑ = when engine speed increase; *N*↓ = when engine speed decrease; CR = compression ratio; PFI = port fuel ignition; SI = spark ignition.

rare fuel cells, hydrogen, NG, DME, electricity, and LPG various properties as well as applications were discussed and highlighted. Some of these fuels are widely accessible and may be used in IC engines with minimal changes, while others need considerable adaptations as well as engine modifications. The authors took on the challenge of demonstrating the development of introducing various fuel types to the market as well as the results from studies into their suitability for use in CI as well as SI engines, which include the polish perspective in this domain. A significant transition in the global effort to use more renewable energy sources and for industrialized nations to lower their net carbon emissions. Using alternative fuels has several advantages for the environment, consumers, and economy. A key motivation for interest in alternative sources of energy is the need to reduce the greenhouse effect. The requirement can be fulfilled by developing alternate motor fuels. Alternative fuels have the potential to play important role in development of automobiles in the future, according to earlier debates. Performance of spark ignition engines during cold starts is significantly improved and carbon monoxide and hydrocarbon emissions are significantly decreased when methanol fuel is added to gasoline. As raising engine power and torque and diminishing specific fuel consumption with ethanol combined with gasoline. A fuel blend of methanol with gasoline represents an increase in both brake torque and power and an improvement in BSFC as compared to regular gasoline. The quantity of oxides of nitrogen (NOx) emissions is reduced with percentage of Ethanol (E) as well as volumetric efficiency may be enhanced by ethanol and gasoline blend.

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