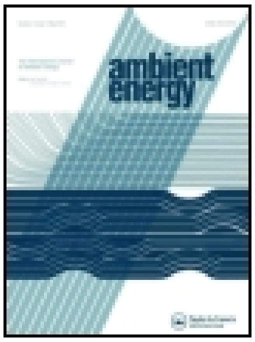

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A detailed study of IC engines and a novel discussion with comprehensive view of alternative fuels used in petrol and diesel engines

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ABSTRACT
The main focus of this manuscript is on to discuss the alternative fuels in IC engines. Important alternative fuels for spark ignition engines are CNG, LPG or propane, alcohols, and hydrogen. Alternative fuels are to be much lower than those of gasoline and diesel-fuelled engines [Dhaliwal, B., N. Yi, and D. Checkel. 2000. 'Emissions Effects of Alternative Fuels in Light-duty and Heavy-duty Vehicles', SAE paper 2000-01-0692]. If there are availability problems with crude oil, due to worldwide geopolitical problems, alternative fuels can also be used as replacements. As of the year 2020, the most commonly used alternative fuel for vehicles is propane, followed by natural gas, and methanol. A number of fuels can be used as an alternative for petroleum-based diesel fuels. One alternative is biodiesel, that is, methyl ester vegetable oils, such as soybean, castor, canola, sunflower, cotton, palm, coconut, Jatropha, and algae oils. Other diesel alternative fuels are dimethyl ether (DME), and Fischer–Tropsch (F–T) fuel. In this manuscript, we discuss the alternative fuel which is most suit for SI engine and CI engine.

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Alternative fuel; CNG; LPG; propane; natural gas and biodiesel

1. Introduction

In this section, we briefly discuss a few of the major figures in the invention and development of the internal combustion engine. The ingenuity and creativity demonstrated by these early engineers in producing these successful inventions are truly inspiring to today's engine designers. In 1858, J. Lenior (1822–1900), a Belgian engineer, developed a two-stroke engine that developed 6 hp with an efficiency of about 5%. During the intake stroke, a gas–air mixture at atmospheric pressure was drawn into the engine, and ignited by a spark, causing the cylinder pressure to increase during the latter half of the stroke, producing work. The return stroke was used to remove the combustion products through an exhaust valve. The Lenior engine was primarily used in stationary power applications (Bass, Bailey, and Jaeger 1993; Devaraj, Devarajan, and Vinoth kanna 2018a; Devaraj et al. 2017).

In 1872, George Brayton (1830–1892), an American mechanical engineer, patented and commercialised a constant pressure internal combustion engine, 'Brayton's Ready Engine'. The engine used two reciprocating piston-driven cylinders, a compression cylinder, and an expansion cylinder. This cycle was also called the 'flame cycle', as the ignition of the gas–air mixture was by a pilot flame, and the mixture was ignited and burned at constant pressure as it was pumped from the compression cylinder to the expansion cylinder. The Brayton piston engine was used on the first automobile in 1878. The Brayton cycle is the thermodynamic cycle now used by gas turbines, which use rotating fan blades to compress and expand the gas flowing through the turbine (Black 1991; Vinoth Kanna 2018a; Vinoth Kanna, Vasudevan, and Subramani 2018c; Subramani and Vinoth kanna 2018).

Nikolaus Otto (1832–1891), a German engineer, developed the 'Otto Silent Engine', the first practical four-stroke engine with in-cylinder compression in 1876. With a compression ratio of 2.5, the gas engine produced 2 hp at 160 rpm, and had a brake efficiency of 14%. Nikolaus Otto is considered the inventor of the modern internal combustion engine, and the founder of the internal combustion engine industry. The concept of a four-stroke engine had been conceived and patented by A. de Rochas in 1861, however, Otto is recognised as the first person to build and commercialise a working flame ignition engine. Otto had no formal engineering schooling, and was self-taught. He devoted his entire career to the advancement of the internal combustion engine. In 1872, he founded the first internal combustion engine manufacturing company, N. A. Otto and Cie, and hired Gottlieb Daimler and Wilhelm Maybach, who would go on to start the first automobile company, the Daimler Motor Company in 1890. Otto's son Gustav founded the automotive company now known as BMW (Cadle et al. 1997; Vinoth Kanna, Devaraj, and Subramani 2018a; Vinoth Kanna, Vasudevan, and Subramani 2018c; Vinoth Kanna and Devaraj 2018).

The first practical two-stroke engine was invented and built by Sir Dugald Clerk (1854–1932), a Scottish mechanical engineer, in 1878. Clerk graduated from Yorkshire College in 1876, and patented his two-stroke engine in 1881. He is well known for his career-long contributions to the improvement of combustion processes in large-bore two-stroke engines. Clerk's engine was made of two cylinders – one a working cylinder to produce

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power, and the other a pumping cylinder to compress and transfer the intake air and fuel mixture to the working cylinder. Poppet valves were used for intake flow, and a cylinder port uncovered by the piston on the expansion stroke was used to exhaust the combustion gases (Clark et al. 1999; Vinoth Kanna and Paturu forthcoming; Vinoth Kanna, Tamil Selvan, and Pinky forthcoming-b; Devaraj, Yuvarajan, and Vinoth Kanna 2018b).

Many of these early internal combustion engines, such as the Lenior, Brayton, and Otto engines, were powered by coal gas, a mixture of methane, hydrogen, carbon monoxide, and other gases produced by the partial pyrolysis of coal. In the 1880s, crude oil refineries began producing gasoline and kerosene in quantities sufficient to create a market for liquid-fuelled internal combustion engines (Hurn and Smith 1951; Vinoth kanna and Pinky 2018a, 2018b; Paturu and Vinoth kanna 2018).

Gottlieb Daimler (1834–1900), a German engineer, is recognised as one of the founders of the automotive industry. He developed a high-speed four-stroke gasoline-fuelled engine in 1883. The liquid fuel was vaporised and mixed with the intake air in a carburetor before being drawn into the combustion chamber. The fuel–air mixture was ignited by a flame tube. In 1886, he built the first four-wheeled automobile, and founded the Daimler Motor Company in 1890 (Dhaliwal, Yi, and Checkel 2000; Fulton et al. 1993; Kato et al. 1999).

Karl Benz (1844–1929), a German engineer, successfully developed a 3.5 hp liquid fuelled two-stroke engine with a carburetor and spark ignition in 1885. The ignition system consisted of an electrical induction coil with a rotary breaker driven by the engine and a removable spark plug fitted into the cylinder head, similar to what is found in today's engines. The engine was installed on a three-wheeled vehicle in 1886, the first 'horseless carriage'. The transmission was a two-chain arrangement that connected the engine to the rear axle (Ikumi and Wen 1981; Nagappan and Vinoth Kanna 2018; Devaraj, Yuvarajan, and Vinoth Kanna 2018b; Subramani and Vinoth kanna 2018).

In 1897, Rudolph Diesel (1858–1913), a German engineer, developed the first practical four-stroke engine using direct injection of liquid fuel into the combustion chamber. The high compression ratio of the engine resulted in autoignition and combustion of the fuel–air mixture. Diesel graduated from Munich Polytechnic in 1880, and worked with his former professor, Carl von Linde, initially on ammonia Rankine cycle refrigeration, then worked with the MAN company to develop compression ignition engines. He designed his engines to follow Carnot's thermodynamic principles as closely as possible. Accordingly, his initial objective was to have constant temperature combustion, however, this was not realised in practice, and he adopted the strategy of constant pressure combustion (Krahl et al. 1996; Lovell 1948; Vinoth Kanna 2018a; Vinoth Kanna, Devaraj, and Subramani 2018a).

Rudolph Diesel's single-cylinder engine had a bore of 250 mm, a stroke of 400 mm, for a 20 L displacement. The diesel fuel was atomised using air injection, a technique where compressed air entrained diesel fuel in the injector and carried it into the cylinder. The engine operated at a speed of 170 rpm, and produced 18 hp, with an efficiency of 27% at full load. This is a much greater efficiency than the steam engines and spark ignition engines in use at that time (Kukkonen and Shelef 1994; Owen and Coley 1995; Devaraj, Devarajan, and Vinoth kanna 2018a).

Sir Harry Ricardo (1885–1974), a mechanical engineering graduate of Cambridge, and a prominent English engineer, patented the use of a spherical prechamber, the Ricardo 'Comet', to greatly increase the fuel–air mixing rate, allowing diesel engines to be used in high–speed, 2000 rpm and higher, engine vehicular applications. The first multi-cylinder diesel engines for trucks were available by 1924, and the first diesel-powered automobiles were available by 1936. During his career, Ricardo also contributed to greater understanding of the role of turbulence, swirl and squish in enhancing flame speed in both spark and diesel engines, commercialised sleeve valves for aircraft engines, developed an octane rating system for quantifying knock in spark engines, and founded what is now the Ricardo Consulting Engineers Company (Malenshek and Olsen 2009; Vinoth Kanna 2018a).

These early engines were air cooled, since they produced relatively low power. Natural convection water-cooling using the thermosyphon principle, and forced convection cooling using water pumps was adopted after about 1910 for higher horsepower engines. For example, Henry Ford's Model T engine of 1908, and the Wright Brother's Flyer engine of 1903 used natural convection water cooling (Midgley and Boyd 1922).

Gasoline and diesel fuels for internal combustion engines are primarily obtained by distillation from petroleum oil. Petroleum oil has a relatively low cost and a high-energy density. It is a fossil fuel composed from ancient organic materials. Formation of petroleum and natural gas reservoirs occurs underground during the pyrolysis of hydrocarbons in a variety of endothermic reactions at high-temperature and/or pressure. Wells are drilled into oil reservoirs to extract the crude oil. In 1858, Edwin Drake drilled the first U.S. oil well, a 21-m deep well in Titusville, Pennsylvania. He is credited with inventing the technique of drilling inside a pipe casing to prevent water seepage. Innovations in the technology for oil recovery have allowed deeper and deeper wells to be drilled. For example, oil is currently pumped from reservoirs about 3000 m below the North Sea seabed in Europe (Bass, Bailey, and Jaeger 1993; Cadle et al. 1997; Kato et al. 1999).

The petroleum industry classifies crude oil by its geographical origin, its API (American Petroleum Institute) gravity (light or heavy), and it's sulfur content (low sulfur is labelled as sweet, and high sulfur is labelled as sour). Light crude oil produces a higher gasoline fraction. Sweet crude oil is more valuable than sour crude oil because it requires less refining to meet sulfur standards. The identified worldwide crude oil reserves are estimated by the American Petroleum Institute to be about 1 trillion barrels, with 0.6 trillion barrels remaining to be identified.

At present consumption rates, at about 30 billion barrels per year, it is estimated that petroleum reserves will last for 60–95 years. Technological advances in extraction have created continual increases in the size of the worldwide petroleum reserves. For example, in 1950 the identified worldwide petroleum reserves were estimated to be about 0.09 trillion barrels, so in the last 60 years, the identified petroleum reserves have increased tenfold. To put the consumption of petroleum into perspective, about 0.7 trillion barrels of petroleum have been consumed since the advent of the industrial revolution. The current U.S. production of crude oil is about 10 million barrels per day. The recent invention and commercialisation of hydraulic fracturing, commonly known as ‘fracking’, has enabled greater production of petroleum and natural gas from underground shale formations (Vinoth Kanna 2018a, 2018b).

Since petroleum contains carbon, its combustion produces carbon dioxide, a greenhouse gas linked to global warming. There are a number of private and governmental initiatives underway to reduce the amount of greenhouse gas emissions from internal combustion engines. These initiatives include increased combustion and process efficiency, and increased use of biofuels. The price of crude oil is dependent on geopolitical factors, and has risen over the last 50 years to a maximum of about $100 the U.S. per barrel. At that price level, alternative fuels such as biodiesel are becoming economically competitive (Vinoth kanna and Pinky 2018a, 2018c).

The earliest internal combustion engines in the late 1800s were fuelled with coal gas. Coal gas is obtained by the coking, that is, partial pyrolysis of coal, similar to the process of producing charcoal from wood. The pyrolysis process drives off the volatile constituents in the coal. Coal gas is typically 50% hydrogen, 35% methane, 10% carbon monoxide, and other trace gases such as ethylene. Coal gas was the primary source of gaseous fuel in the United States until replaced by natural gas in the 1940s. Use of gaseous fuels such as methane for internal combustion engines is increasing, due to increased availability and relatively lower emissions relative to liquid fuels (Devaraj, Yuvarajan, and Vinoth Kanna 2018b; Vinoth kanna and Subramani forthcoming).

Table 1. Knock characteristics of single-component fuels.

Formula	Name	Compression ratio	Octane number research	Motor
CH4	Methane	12.6	120	120
C2H6	Ethane	12.4	115	99
C3H8	Propane	12.2	112	97
C4H10	Butane	5.5	94	90
C4H10	Isobutane	8.0	102	98
C5H12	Pentane	4.0	62	63
C5H12	Isopentane	5.7	93	90
C6H14	Hexane	3.3	25	26
C6H14	Isohexane	9.0	104	94
C7H16	Heptane	3.0	0	0
C7H16	Triptane	14.4	112	101
C8H18	Octane	2.9	−20	−17
C8H18	Isooctane	7.3	100	100
C10H12	Isodecane		113	92
C4H8	Methylcyclopropane		102	81
C5H10	Cyclopentane	12.4	101	95
C6H12	Cyclohexane	4.9	84	78
C6H12	1,1,2-trimethylcyclopropane	12.2	111	88
C7H14	Cycloheptane	3.4	39	41
C8H16	Cyclooctane		71	58
C6H6	Benzene			115
C7H8	Toluene	15	120	109
C8H10	Ethyl benzene	13.5	111	98
C8H10	*m*-Xylene	15.5	118	115
C3H6	Propylene	10.6	102	85
C4H8	Butene-l	7.1	99	80
C5H10	Pentene-l	5.6	91	77
C6H12	Hexene-l	4.4	76	63
C5H8	Isoprene	7.6	99	81
C6H10	1,5-Hexadiene	4.6	71	38
C5H8	Cyclopentene	7.2	93	70
CH4O	Methanol		106	92
C2H6O	Ethanol		107	89

2. Gasoline fuels

Gas has been the predominant vehicular fuel since the mid-1900s. It has an extremely high volumetric vitality thickness and a moderately minimal effort. It is a mix of light refined hydrocarbons, which additionally incorporates naphthenes, olefins, paraffins, and aromatics. It has a hydrogen to carbon proportion changing from 1.6 to 2.4. An average recipe used to portray fuel is C8H15, with an atomic load of 111. A high hydrogen content fuel is C7H17.

Fuel properties of enthusiasm for inward burning motors are given in Table 1. The properties incorporate the octane number, instability, gum content, thickness, explicit gravity, and sulfur content. The ASTM has built up a lot of fuel details for every property, additionally recorded in Table 1. The AKI is the normal of the examination (D2699) and motored (D2700) octane numbers, and it is shown on fuel siphons at administration stations (e.g. 85, 87, and 91).

For a long time, the octane number of fuels was over 90, and achieved a maximum during the 1960s, with leaded premium gas accessible with AKI evaluations of 103+. Starting at 2014, standard gas has a 87 AKI octane.

The octane number for flying powers depends on the motored (D2700) and super-charged (D909) test strategies. Learning of gas unpredictability is critical not just in planning fuel conveyance and metering frameworks, yet additionally in controlling evaporative outflows. The instability is evaluated by three related details: (1) the distillation bend (D86), (2) the Reid vapour weight (D323), and (3) the vapour – fluid proportion (D439). With the D86 refining technique, a still is utilised to dissipate the fuel. The fuel vapour is consolidated at the climatic weight. The warming rate is balanced ceaselessly to such an extent that the buildup rate is 4–5 mL/min. The warming procedure is ceased when the fuel begins to smoke and break down, regularly around 370°C. The vapour temperature at the highest point of the refining cup is estimated all through the test. The volume portion of condensate is plotted versus temperature to shape 90, are utilised in the instability particulars. The T a refining bend. The 10% and 90% dissipation temperatures, T 10 and T 10 temperature, showing the beginning of vaporisation, is utilised to portray the virus beginning conduct, and the T 90 temperature, demonstrating the completion of vaporisation, is utilised to describe the likelihood of unburned hydrocarbons.

The ASTM drivability index (DI) is also a measure of fuel volatility and is defined in Equation (1) as

$$\mathrm{DI} = 1.5T10 + 3T50 + T90 \qquad (1)$$

Gum is a result of oxidation responses with specific atoms regularly found in energises. Utilisation of gas with a high gum part can prompt staying of valves and cylinder rings, carbon stores, and obstructing of fuel metering openings. Inhibitors are frequently added to gas to diminish the gum shaped in such a test under a supposition that they will likewise decrease gum arrangement in administration. The ASTM D381 test strategy includes vanishing 50 mL of fuel in a glass dish at around 430 K by ignoring warmed air the example for a time of around 10 min.

Table 2. Gasoline property specifications.

Property	ASTM method
Benzene, vol%	D3606
Distillation, K	D86
Gum, mg/mL	D381
Heating value	D240
Hydrocarbons, %	D1319
Octane, motored	D2700
Octane, research	D2699
Octane, supercharged	D909
Reid vapour pressure, kPa	D323
Specific gravity	D287
Sulfur, wt%	D1266

The distinction in load of the dish when the test is known as the existent gum content.

2.1. Gasoline additives

Gas added substances incorporate octane improvers, hostile to ices to avoid fuel line solidify up, cleansers to control stores on fuel injectors and valves, erosion inhibitors, and cell reinforcements to limit gum arrangement input away gas. Alcohols, ethers, and methyl cyclopentadienyl manganese tricarbonyl (MMT) are currently utilised as octane improvers.

Numerous mixes have been tried for use as octane improvers in fuel. Tetraethyl lead was the essential octane improver as a rule use from 1923 to 1975. Its utilisation in engine vehicles was denied in 1995 because of its danger and antagonistic impact on exhaust systems and oxygen sensors. As of now, lead is just utilised in flying and go dirt road romping dashing fuels. Thomas Midgley (1889–1944), a mechanical designer from the General Motors Research Laboratory, found lead added substances in 1921, as delineated in (Midgley) (and) (Boyd) (1922). Midgley additionally was the innovator of Freon (F-12), a refrigerant at first created for car cooling frameworks. Freon was the most broadly utilised refrigerant on the planet until the mid-1990s when it was discouraging mined that the bright decay of Freon in the stratosphere discharges chlorine, causing consumption of the stratospheric ozone layer. The assembling of Freon in the United States was denied in 1998 (Table 2).

3. Alternative fuels for spark ignition engines

Essential elective fills for start motors are CNG, propane or LPG, alcohols, and hydrogen. Elective powers are of consideration, since they can be cleaned from sustainable feedstocks, and their outflow levels can be much lower than those of gas and diesel-energised motors (Dhaliwal, Yi, and Checkel 2000).

On the off chance that there are accessibility issues with unrefined petroleum, because of worldwide geopolitical problems, elective fills can likewise be utilised as substitutions. As of the year 2015, the most ordinarily utilised elective fuel for vehicles is propane, trailed by petroleum gas, and methanol. The expense of elective energises per unit of vitality conveyed can be more noteworthy than gas or diesel fuel, and the vitality thickness of elective powers by volume is not as much as gas or diesel fuel. The littler volumetric vitality thickness requires bigger fuel stockpiling volumes to have indistinguishable driving reach from gas energised vehicles. This can be a downside, especially with double fuel vehicles, where a significant not bit of the storage compartment space is utilised by the elective fuel stockpiling tank. Alternative energises likewise come up short on a wide-scale circulation and filling framework practically identical to that of customary powers. Lately, armada vehicles, for example, transports, trucks, and vans have been a developing business sector for elective powers, as they can work satisfactorily with confined energising. In 1990, there were around 4 million propane-filled vehicles, 3 million ethanol-powered vehicles, and around 1 million gaseous petrol energised vehicles around the world, contrasted and around 150 million gas energised vehicles in the United States alone.

Existing gas or diesel motors can be retrofitted reasonably effectively for activity with elective fills. Be that as it may, different operational contemplations should be considered. The distinctive burning qualities of elective fills require an adjustment in the infusion and start timing. Additionally, numerous elective fills, particularly those in vaporous shape, have low lubricity, causing expanded wear of fuel components, for example, fuel injectors and valves.

The properties of different elective energise are organised in Table 3, and are compared with the properties of *n* – octane. The initial three sections contain vaporous fills (methane, propane, and hydrogen) and the following three segments are fluid energises (methanol, ethanol, and *n* – octane). While there is a scope of vitality densities on a fuel mass (MJ/kg fuel) premise, the vitality densities are tantamount on a stoichiometric air mass (MJ/kg air) premise. Octane has the best vitality thickness by volume (MJ/L). Exchange powers have higher octane levels than gas, so motors filled with modify local energises can work at higher pressure levels, and consequently at higher productivity. Additional data about elective fills and their utilisation is given in Owen and Coley (1995).

The methane number is a proportion of the inclination for a vaporous fuel to thump. As demonstrated in Table 4, Malenshek and Olsen (2009) found a straight relationship between the most extreme pressure proportion and the methane number, for an assortment of vaporous powers, including coal gas, wood gas, digester gas, and landfill gas. A fuel's methane number restrains the greatest pressure proportion and, in this way, the hypothetical motor productivity. For instance, a motor streamlined to work on flammable gas with a methane number of around 90 is defenseless to thump when worked on gases that have a lower methane number, for example, coal gas which has a methane number of 24. The octane number of methane is 120 (RON), one of the most astounding qualities for hydrocarbon energises.

3.1. Propane

Propane (C3H8), is a soaked paraffinic hydrocarbon. At the point when mixed with butane (C4H10) or ethane (C2H6), it is likewise assigned as condensed oil gas. A common LPG mix is P92, which is 92% propane and 8% butane. In the United States, around one-portion of the LPG supply is gotten from the lighter hydrocarbon parts delivered amid raw petroleum refining, and the other half from heavier segments of wellhead flammable gas. Propane has been utilised as a vehicular fuel since the 1930s. In 1993, there were around 4 million LPG vehicles working around

Table 3. . Thermodynamic properties of spark ignition fuels.

	Propane	Natural gas	Hydrogen	Methanol	Ethanol	Gasoline
Molecular weight	44.10	18.7	2.015	32.04	46.07	~ 110
Boiling point (°C), at 1 bar	−42	−160	−253	65	78	30–225
Mass A/F ratio,	15.58	17.12	34.13	6.43	8.94	15.04
Stoichiometric vapour pressure (kPa), at 32°C				32	17	62–90
Enthalpy of vapourisation, âĎŐ fg (kJ/kg), at 298 K				1215	850	310
Adiabatic flame temperature (K)	2268	2227	2383	2151	2197	2266
Vapour flammability limits (% volume)	2.1–9.5	5.3–15	5–75	5.5–26	3.5–26	0.6–8
Lower heating value, mass, (MJ/kgfuel)	46.4	50.0	120	6	26.8	44.5
Lower heating value, volume, (MJ/kgfuel)	25.5	8.1		15.7	21.1	32.9
Lower heating value, stoichiometric (MJ/kgair)	2.98	2.92	3.52	3.09	3.00	2.96
Octane number, research	100	120	106	112	111	90–98
Octane number, motor	95.4	120		91	92	80–90
Stoichiometric CO_2 emissions, (g CO_2/Mjfuel)	64.5	54.9	0	69	71.2	71.9

Source: Adapted from Black (1991).

Table 4. Critical compression ratio versus methane number.

Gas	Compression ratio	Methane number
Coal gas	8.0	23.9
Steam-reformed natural gas	10.5	62.4
Wood gas	10.3	70.2
Natural gas		78–98
Methane	14.4	100
Digester gas	17.6	139.1
Landfill gas	17.6	139.6

Source: Malenshek and Olsen (2009).

Table 5. LPG-fuelled vehicle (3.1 L engine) emissions.

	Propane	Gasoline
Regulated emissions (g/mile)		
HC	0.21	0.37
CO	2.55	5.4
NO*x*	0.67	0.42
Toxic emissions (mg/mile)		
Benzene	< 0.1	16.7
1,3-Butadiene	< 0.1	2.5
Formaldehyde	1.2	3.1
Acetaldehyde	0.3	1.5
Total	1.5	23.8

Source: Bass, Bailey, and Jaeger (1993).

Table 6. CNG-fuelled vehicles (2.2 L engine) regulated emissions (g/mile).

Emission	Toyota engine	GMC engine	GMC engine
	CNG	CNG	Gasoline
NMOG	0.007	0.027	0.08
CO	0.69	1.01	1.54
NO*x*	0.015	0.10	0.17

Source: Kato et al. (1999).

the world, with the dominant part in the Netherlands, trailed by Italy, the United States, and Canada. There is a relatively broad refuelling system for propane, with more than 15,000 refuelling stations accessible in North America. There are various unique hardware producers that presently move propane-energised vehicles, principally light- and medium-obligation armada vehicles, for example, get trucks and vans. Transformation units are additionally accessible to convert gas or diesel-powered motors to devoted propane or double fuel use.

In vehicles, propane is put away as a compacted fluid, regularly from 0.9 to 1.4 MPa. Its evaporative discharges are basically zero, since it is utilised in a fixed framework. A weight controller controls the supply of propane to the motor and changes over the fluid propane to a gas through a throttling procedure. Propane gas can be infused into the admission complex, into the ports, or specifically into the chamber. Propane has an octane number of 112 (RON), so vehicular uses of propane can work at a raised pressure proportion.

As appeared in Table 9.6, the CO_2 emanations on an identical vitality premise are about 90% that of fuel. Fluid propane has three-fourths of the vitality thickness by volume of gas with the goal that the mileage is correspondingly decreased. The volumetric effectiveness and the power are additionally diminished because of the removal of around 5–10% of the admission air by propane and the loss of evaporative charge cooling. Propane requires around a 5-start advance at lower motor speeds because of its generally low fire speed.

Agent FTP emanations from an LPG-filled motor are appeared Table 5. The motor utilised was a 3.1 L motor with an LPG transformation framework utilising an admission mani-overlay blender. The LPG fuel utilised was HD5 propane (96% propane and 4% ethane). The outcomes show that the HC and CO discharges were bring down with LPG than gas, 43% and 53% individually, however, the NO*x* levels were higher. The dangerous emanations are additionally given in Table 5. The dimensions of harmful outflows are regularly a request of size not exactly the standard fuel dangerous discharges.

3.2. *Natural gas*

Petroleum gas is a normally happening fuel found in oil fields. It is basically made out of around 90–95% methane (CH4), with little measures of extra mixes, for example, 0–4% nitrogen, 4% ethane, and 1–2% propane. Methane is an ozone harming substance, with a dangerous atmospheric devation potential around multiple times that of carbon dioxide. As appeared in Table 9.6, since methane has a lower carbon to hydrogen proportion in respect to gas, its CO_2 discharges are around 22–25% lower than fuel (Tables 6–9).

Petroleum gas has been utilised for a long time in stationary motors for gas pressure and electric power age. A broad dispersion system of petroleum gas pipelines exists to address the issue for gaseous petrol for mechanical procedures and warming applications. Gaseous petrol-powered vehicles have been being used since the 1950s, and change packs are accessible for both

Table 7. CNG-fuelled vehicles toxic emissions (mg/mile).

Toxic	CNG	CNG start/gasoline run	Gasoline
Benzene	0.2	14.8	31.2
1,3-Butadiene	60.1	0.1	1.5
Formaldehyde	3.4	4.1	5.9
Acetaldehyde	0.2	0.3	2.0
Total	3.8	19.3	40.6

Source: Kukkonen and Shelef (1994).

Table 8. Heavy-duty natural gas engine emission certification data (g/bhp-h).

	Hercules GTA 5.6	Cummins L10	Detroit Diesel 50G
Power (hp)	190	240	275
NMHC	0.9	0.2	0.9
CO	2.8	0.2	2.8
NO*x*	2.0	1.4	2.6
PM	0.10	0.02	0.06

Source: Owen and Coley (1995).

Table 9. FTP toxic emissions (mg/mile) from ethanol-fuelled vehicles.

Toxic	E85	Phase 2 RFG
Benzene	1.8	5.1
1,3-Butadiene	0.2	0.7
Formaldehyde	4.1	2.1
Acetaldehyde	24.8	0.5
Total	20.7	8.4

Source: Cadle et al. (1997).

Table 10. Toxic emissions (mg/mile) from methanol-fuelled vehicles.

Toxic	M85	Phase 2 RFG
Benzene	3.0	6.0
1,3-Butadiene	0.10	0.6
Formaldehyde	17.1	1.6
Acetaldehyde	0.5	0.4
Total	20.7	8.6

Source: Cadle et al. (1997).

start and pressure start flammable gas and gas or diesel fuel. Starting in 2013, there are around 18 million flammable gas filled street vehicles around the world, and the quantity of gaseous petrol energised vehicles is required to twofold by 2020. One favourable position of a biofuel task is that the working scope of a vehicle is reached out in correlation with a devoted gaseous petrol vehicle. At present, unique hardware makers are moving generation petroleum gas filled vehicles, fundamentally to armada proprietors. Petroleum gas vehicles were the primary vehicles to meet the California ULEV emanation benchmarks.

Petroleum gas is put away in a compacted (CNG) state at room temperatures and furthermore in a fluid (LNG) shape at 160°C. Gaseous petrol has an octane number (RON) of around 120 with the goal that flammable gas motors can work at a pressure proportion higher than that of gas filled motors. Petroleum gas is pressurised to 20 MPa in vehicular capacity tanks with the goal that it has around 33% of the volumetric vitality thickness of gas. The capacity weight is around multiple times that of propane. Like propane, gaseous petrol is delivered to the motor through a weight controller, either through a blending valve situated in the admission complex, port fuel infusion at around 750 kPa, or direct infusion into the barrel. With admission complex blending or port fuel infusion, the motor's volumetric proficiency and power are decreased because of the dislodging of about 10% of the admission air by the flammable gas, and the loss of evaporative charge cooling. Petroleum gas does not require blend improvement for virus beginning, decreasing potential virus begin HC and CO outflows.

The burning of methane is not the same as that of fluid hydrocarbon ignition, since just carbon–hydrogen bonds are included, and no carbon–carbon bonds, so the burning procedure is bound to be increasingly finished, creating less non-methane hydrocarbons. Optimal thermal efficiency occurs at rich conditions with equivalence ratios of 1.3–1.5. The total hydrocarbon emission levels can be higher than gasoline engines due to unburned methane. The combustion of methane can produce formaldehyde, a regulated toxic pollutant. The particulate emissions of natural gas are very low relative to diesel fuel.

Natural gas has a lower adiabatic flame temperature (2240 K) than gasoline (2310 K), due to its higher product water content. Operation under lean conditions will also lower the peak combustion temperature. The lower combustion temperatures lower the NO formation rate, and produce less engine-out NO*x*.

3.3. Ethanol

Ethanol (C_2H_5OH) is a liquor fuel framed from the maturation of sugar and grain stocks, essentially sugar stick and corn, which are sustainable power sources. Its properties and burning attributes are fundamentally the same as those of methanol. Ethanol is likewise called 'grain' liquor. It is a fluid at surrounding conditions and nontoxic at low focuses.

Gasohol (E10) is a gas–ethanol mix with about 10% ethanol by volume. E85 is a mix of 85% ethanol and 15% gas. In Brazil, about portion of the vehicles utilise an ethanol-based fuel 'liquor', basically E93, delivered from sugar stick. In the United States, the essential wellspring of ethanol is as of now from starch feedstocks, for example, corn, and there are endeavours in progress to create ethanol from cellulosic feedstocks, for example, corn fibre, ranger service waste, poplar, and switch grass. The vitality thickness by volume of ethanol is generally high for an elective fuel, around 66% that of gas. The octane rating of ethanol of 111 RON permits utilisation of an expanded compression proportion. The cetane number of ethanol is low, at around 8, and it very well may be utilised in pressure start motors with diesel fuel pilot start. As shown in Table 3, the CO_2 emissions from ethanol on an equivalent energy basis are about 99% that of gasoline. With a switch from RFG to E85, for a fleet of flexible fuelled vehicles, Cadle et al. (1997) report that the NO*x* emissions decreased by 29%, the nonmethane hydrocarbons (NMHC) decreased by 10%, and the CO emissions increased by 8%. The corresponding FTP toxic emissions are shown in Table 10. There was a 71% reduction in 1,3-butadiene, and a 64% reduction in benzene. However, for E85 the acetaldehyde emissions were almost two orders of magnitude higher than those of RFG, leading to almost a fourfold increase in the toxic emission levels.

3.4. Methanol

Methanol (CH_3OH) is an alcohol fuel formed from natural gas, coal, or biomass feedstock. Methanol has been used as a vehicular fuel since the early 1900s, and is also used as a fuel for diesel engines and fuel cells. It is also called wood alcohol. It is a liquid at ambient conditions. Its chemical structure is a hydrocarbon molecule with a single hydroxyl (OH) radical. The hydroxyl radical increases the polarity of the hydrocarbon so that methanol is miscible in water, and has a relatively low vapour pressure. Since oxygen is part of the chemical structure, less air is required for complete combustion. Methanol is very toxic, and ingestion can cause blindness and death.

Pure methanol is labelled M100, and a mix of 85% methanol and 15% gasoline is labelled M85. M85 has an octane rating of 102. Adding gasoline to methanol provides more volatile components that can vaporise more easily at low-temperatures. Methanol has been adopted as a racing fuel, both for performance and safety reasons. Since methanol mixes with water, a methanol fire can be extinguished with water, which is not the case with gasoline. The octane rating of methanol M100 of 111 RON allows use of an increased compression ratio. The relatively high enthalpy of evaporation (1215 kJ/kg) of methanol relative to gasoline (310 kJ/kg) produces greater intake air-cooling and a corresponding increase in volumetric efficiency relative to gasoline. The energy density by volume of methanol is about half that of gasoline. However, because of its oxygen content, it has a higher stoichiometric energy density (3.09 MJ/kg air) relative to gasoline (2.96 MJ/kg air).

For maximum power, a rich equivalence ratio of $\phi = 1.6$ is used. Flexible-fuel vehicles (FFV) have been developed to use a range of methanol and gasoline blends ranging from 100% gasoline to M85. An optical fuel sensor is used to determine the alcohol content and adjust the fuel injection and spark timing. The engine compression ratio is not increased, to allow for the lower octane level of gasoline. The low vapour pressure of methanol causes cold starting problems. Satisfactory cold starting with M85 requires a rich mixture so that enough volatiles are present to form a combustible mixture.

Methanol is corrosive, especially to rubber and plastic, so alcohol tolerant components, such as stainless steel, are required for its storage and transport. The cetane number of methanol is low at about 5, and it can be used in compression ignition engines with diesel fuel pilot ignition. Methanol burns with a nearly invisible flame, and a relatively high flame speed. Formaldehyde is a significant decomposition product from methanol combustion and is expected to be higher from methanol than other fuels.

The formaldehyde emissions are proportional to the equivalence ratio, so rich combustion will produce increased emissions of formaldehyde. Special lubricants also need to be used in methanol-fuelled engines.

As shown in Table 9.6, the CO_2 emissions of methanol on an equivalent energy basis are about 96% that of gasoline. With a change in the fuel for a fleet of flexible-fuelled vehicles from RFG to M85, the nonmethane hydrocarbons (NMHC) and CO emissions decreased by 30% and 17% respectively, and the NO*x* emissions remained about the same (Cadle et al. 1997). The FTP toxic emissions for the methanol- and gasoline-fuelled-flexible fuelled vehicles are given in Table 11. There was an 83% reduction in 1,3-butadiene, a 50% reduction in benzene, and a 25% increase in acetaldehyde. However, for M85 the formaldehyde emissions were almost an order of magnitude higher than those of RFG, leading to more than a twofold increase in the toxic emission levels.

3.5. Hydrogen

Hydrogen (H_2) can be produced from many different feedstocks, including natural gas, coal, biomass, and water. The production processes include steam reforming of natural gas, presently the most economical method, electrolysis of water, and gasification of coal, which also produces CO_2. Hydrogen is colourless, odourless, and nontoxic, and hydrogen flames are invisible and smokeless. The global warming potential of hydrogen is insignificant in comparison to hydrocarbon-based fuels, since combustion of hydrogen produces no carbon-based compounds such as HC, CO, and CO_2.

At present, the largest user of hydrogen fuel is the aerospace community for rocket fuel. Hydrogen can also be used as a fuel in fuel cells. There have been a number of vehicular demonstration projects, but the relatively high cost of hydrogen fuel has hindered adoption as an alternative fuel. Dual fuel engines have been used with hydrogen, in which hydrogen is used at start up and low load, and gasoline at full load (Fulton et al. 1993) to reduce the cold start emissions levels.

One of the major obstacles related to the use of hydrogen fuel is the lack of any manufacturing, distribution, and storage infrastructure. The most economical method would be to distribute hydrogen through pipelines, similar to natural gas distribution. The three methods used to store hydrogen are: (1) in a liquid form at −253°C in cryogenic containers, (2) as a metal hydride, such as iron – titanium hydride FeTiH2, or (3) in a pressurised gaseous form at 20–70 MPa. The metal hydride releases hydrogen when heated by a heat source, such as a vehicle exhaust system. The most common storage methods are liquid and hydride storage, which have comparable volumetric storage capabilities, both requiring about 10 times the space required by an equivalent 5-gallon gasoline tank, as shown by Table 11.

At least a 55-gallon tank of compressed hydrogen is needed to store the energy equivalent of 5 gallons of gasoline.

Compressed hydrogen at 70 MPa has one-third the energy density by volume of compressed natural gas, and liquid hydrogen has one-fourth the energy density by volume of gasoline. Use of liquid hydrogen has an additional energy cost, as liquefaction of hydrogen to −20 K requires an expenditure of energy approximately equal to the energy content of liquid hydrogen. If mixed with air in the intake manifold, the volume of hydrogen is about 30% of the intake mixture volume at stoichiometric, decreasing the volumetric efficiency.

The octane rating of hydrogen of 106 (RON) allows use of an increased compression ratio. The combustion characteristics of hydrogen are very different from gasoline combustion characteristics, as the laminar flame speed of a hydrogen–air mixture is about 3 m/s, about 10 times that of methane and gasoline, and the adiabatic flame temperature is about 100°C higher than gasoline and methane. Since it has a wide flammability limit (5–75%), preignition and backfiring can be a problem. The flammability limits correspond to equivalence ratios of from 0.07 to 9.0. Water injection into the intake manifold is used to mitigate preignition and provide cooling. Exhaust gas recirculation and lean operation are used to reduce NO*x* levels.

Table 11. Comparison of hydrogen storage methods.

	Gasoline (5 gallons)	Liquid H_2	Hydride Fe Ti (1.2%)	Compressed (70 MPa) H_2
Energy (kJ)	6.64×10^5	6.64×10^5	6.64×10^5	6.64×10^5
Fuel mass (kg)	14	5	5	5
Tank mass (kg)	6.5	19	550	85
Total fuel system mass (kg)	20.5	24	555	90
Volume (gal)	5	47	50	60

4. Alternative fuels for compression ignition engines

A number of fuels can be used as an alternative for petroleum-based diesel fuels. One alternative is biodiesel, that is, methyl ester vegetable oils, such as soybean, castor, canola, sunflower, cotton, palm, coconut, Jatropha, and algae oils. Other diesel alternative fuels are dimethyl ether (DME), and Fischer–Tropsch (F–T) fuel.

Biodiesel fuels are designated with the prefix B, so a mixture of 20% biodiesel is labelled B20. A number of the U.S. states have mandated the use of biodiesel, and the levels vary by state, from B2 to B20. Diesel engines are rated for a maximum percentage of biodiesel, typically from B5 to B20. The most common blend in the United States is B20.

In Europe, diesel fuel is blended with 7% biodiesel to produce B7. Biodiesel is also a ULSD (Ultralow sulfur diesel) because it contains very low levels of sulfur. Biodiesel fuels are produced through the transesterification of triglycerides in vegetable oil using a low molecular weight alcohol, such as methanol. The methyl ester is obtained through a process in which methyl alcohol and a catalyst (such as sodium hydroxide or potassium hydroxide) chemically breaks down the triglyceride molecule into methyl esters of the oil and a glycerin byproduct. Biodiesel is not a single chemical compound, as the triglycerides in vegetable oils are a variable mixture of unsaturated and saturated fatty acids. The interest in algae-based biodiesel has been increasing, due to the far greater sunlight – oil conversion efficiency of algae relative to land-based crops.

Fischer–Tropsch (F–T) fuel is produced from a mixture of CO and H_2 using a catalytic reforming process with iron or cobalt. The CO is generated by pyrolysis of woody materials, such as switchgrass. The Fischer–Tropsch reaction is a water–gas reaction:

$$nCO + (2n + 1)H_2 \rightarrow CnH_2n + 2 + nH_2O \quad (2)$$

Dimethyl ether (DME) is an oxygenated fuel produced by dehydration of methanol or from synthesis gas. The volumetric energy density (MJ/L) of DME is about half that of diesel fuel. It burns with a visible blue flame, similar to that of natural gas. It is noncorrosive to metals but does deteriorate some elastomers.

Alternative diesel fuels have a higher cost, and lower volumetric energy density than fossil-based diesel fuel, but do produce lower CO and particulate emissions. Numerous studies have shown slightly greater NO*x* levels from diesel engines fuelled with biodiesel relative to petroleum-based diesel. For example, Krahl et al. (1996) report that RME had about 40% lower HC emissions, 35% lower CO, 35% lower PM, but about 15% greater NO*x* emissions. One explanation is that the oxygen atoms in the biodiesel molecule give rise to a leaner premixed ignition zone during combustion resulting in increased combustion temperatures.

Clark et al. (1999) measured the transient emissions of a number of blends of Fischer–Tropsch fuel. All of the regulated emissions were lower in comparison with low-sulfur diesel fuel, with 43% lower HC emissions, 39% lower CO, 14% lower PM, and 14% lower NO*x* emissions.

5. Conclusion

Gas for start motors and fuel oil or diesel oil for blower start motors have been utilised as a principle fuel that have been utilised in inward burning motors for the majority of the twentieth century. For twentieth century motors require an elective fuel having a development of arrangement and added substances. In the ongoing period, liquor fills got from various grange items and some extra sources have turned out to be dynamically progressively noteworthy, in all nations in light of expanding air contamination issues and fuel emergency, for which innovative work programmes are being directed all through the world to discover or meet reasonable interchange energises which will conquer fuel emergency and contamination less fuel to the motor needs.

Disclosure statement

No potential conflict of interest was reported by the authors.

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