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A Review on the Prospects of Various Gaseous Fuel as an Automotive Fuel and for Reducing Environmental Pollution

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Abstract: For many decades, Ethanol has been used as Engine fuel as it has properties very similar to petrol, that make ethanol usable in engines with minor hardware modifications. It burns cleaner and is being blended in various ratios with petroleum origin transportation fuel all over the world. To overcome the ethanol shortage and in search for clean fuels, manufacturers shifted towards gaseous fuels like Liquified Petroleum Gas (LPG), Natural Gas, Methane, etc. Gaseous fuels are preferred over solid/liquid fuels as they give very less emissions. Biogas produced from organic waste is a promising alternative and renewable gaseous fuel which can be explored for use in IC engines. This review work provides a detailed summary of the work done in the gaseous fuel domain and particularly Bio-gas domain for its uses in IC engines. A substrate of Cow Dung mixed with other biowastes like rice husk or vegetable peelings can satisfactorily achieve a yield hike of 44% under controlled conditions. Presence of certain special microbes or catalyst the augments biogas generation. Biogas digesters fed with a substrate of 25% cow dung and 75% food waste reported 80% higher yield. Results of using this biogas mixed with CNG in engines is also elaborated.

Keywords: Green Energy, Renewable Gaseous fuel, Biowaste, Biogas, Engine emissions.

1. Introduction

Current global population has crossed the mark of 7.9 billion as of September 2022 and still counting. The population, being the single most influential factor has led to a huge increase in demand for energy. The development of civilization, lifestyle and economic expansion will all contribute to an increase in the nation's energy requirement. This increasing demand for energy is a matter of concern which needs to be properly taken control of[1]. According to sources, India imports about 85% of its oil. India being the third largest consumer of energy is heavily dependent on imports for fulfilling the demands of fuels such as petroleum, crude oil, etc. The dependence on fossil fuels mainly coal is growing as it is one of the most important and abundant fossil fuels in India. Due to the burning of fossil fuels, various harmful compounds such as oxides of nitrogen and sulphur are released into the atmosphere which increases pollution[2]. Vehicles are another major source of air pollution. Internal combustion engines emit greenhouse gases, lead to climate change, harm our environment, badly affect human health, and may lead heart related issues and lung disorders. Nonetheless, engines remain an important component of the world's energy supply, helping to fulfil demand in all industries Significant attempts are now being made by researchers to improve the internal combustion engines to lower their fuel consumption, CO_2 emissions, range, durability, and lifetime, as well as their comfort[3]. Use of renewable energy sources have shown rapid progress in various countries in last decade. It was analysed, earlier research analysing numerous nations for the existence of the Green Paradox and demonstrated that there is no set of uniform criteria to determine whether or not the Green Paradox exists. This is based on the earlier research perspectives of power pricing, the introduction of renewable energy, and the percentage of overseas production[4]. To control pollution engineers are looking out for cleaner and greener fuels.

For many decades, humans have been utilizing ethanol as fuel. Ethanol has properties very similar to gasoline that make ethanol usable in engines with minor hardware modifications. It burns cleaner and has much lesser emissions as compared to gasoline. Ethanol (C_2H_5OH) is a by-product of biomass fermentation of starch-based plants. Bioethanol has a high potential for use as engine fuel can be safely used for blending with gasoline. Such blends give significantly lower emissions, reduce knocking in SI engines and exhibit more consistent pressure inside the cylinder. Furthermore, the high concentration of oxygen in ethanol reduces CO and HC emissions while marginally increases CO_2 emissions[5].

In comparison to gasoline, a 5% ethanol blend in gasoline is found to increase the octane number of the fuel, resulting in increased power and torque while decreasing specific fuel consumption. This high-octane number also supports its antiknock properties. Also, high octane number of blend allows it to be used at higher compression ratios thus increasing overall engine Efficiency. That's why ethanol gasoline blends were more efficient as fuel than pure gasoline[6)]. Ethanol and petrol are already being blended in various ratios with transportation fuel of petroleum origin all over the world as an environmentally beneficial and sustainable alternative[7)]. Due to ethanol scarcity, India could only blend 5-10% ethanol with petrol. To address the ethanal shortage, we must shift to gaseous fuels. A blend containing more than 20% ethanol, on the other hand, would have phase and stability issues as well[8, 9)].

Gaseous fuels abundantly available include Liquified Petroleum Gas (LPG), Natural Gas, Compressed Natural Gas (CNG), Methane, Propane etc. Gaseous fuels mainly comprise carbons, hydrocarbons etc. Gaseous fuels are preferred over solid/liquid fuels as they produce very less emissions in engines[10)].

LPG was used as a portable fuel source in the early 1860s. It consists of propane, butane, propylene, butylene, and isobutane. LPG being easy to transport is readily preferred over solid/liquid fuels. It has very less amount of sulphur, so it burns a lot cleaner. It is more eco-friendly as compared to other sources of energy. But there are disadvantages of LPG as well. In case of leaking, it causes suffocation which might lead to various lung diseases. It is inflammable. It is not viable in mountainous or rough terrains as it provides less power. Also, it is reported to have severe fire hazards[10)].

Natural gas, a naturally occurring combination of hydrocarbons primarily composed of methane, has the potential to replace conventional hydrocarbon-based fuels. Low levels of gaseous emissions of CO_2, CO, nitrogen oxides, and sulphur have been seen when methane is used. It has a 92% efficiency rate. However, there are a few limitations to the vast use of CH_4 such as low energy density and the requirement of using a very high-pressure storage or it is stored as liquefied gas[11-12)].

In 1993, CNG was introduced in India as a gaseous fuel. It was made up of 93.05% of methane, nitrogen, carbon dioxide, propane, and traces of ethane. It is used as a daily usage fuel i.e., can be used both for commercial and domestic use. CNG proves as a very clean fuel due to lesser toxic emissions, on burning it emits significantly less HC than gasoline and the chances of mishaps caused by CNG is far lesser than LPG fuel. It has some drawbacks as well. At high speeds, CNG produces more NOx than gasoline. Also, the CNG filling stations are very limited thus it is not yet readily available for larger usage in India. Another big drawback of CNG is the lower engine power and hence poor performance compared to gasoline[13)].

This problem of reduced engine power is addressed by mixing little amount of Hydrogen gas in CNG. A mixture of Hydrogen in CNG can significantly improve the engine power and hence the performance relative to pure CNG. The calorific value of CNG gets increased with Hydrogen which increases the travelling range as well but very careful handling of fuel is required as Hydrogen is highly explosive. The addition of a trace of hydrogen is reported to have improved the engine performance, cylinder pressures and emissions at low engine speeds. Running a hydrogen engine with a lean air-fuel mixture stabilizes the combustion processes and makes the engine run smoother, but it reduces engine performance by lowering the Indicated Mean Effective Pressure. Also, due to the low density of hydrogen, the energy carried per unit volume of fuel is less than that of other fuels[14, 15)]. But H_2 being highly reactive, can cause fatal accidents if higher amounts of H_2 are blended and can also make the mixture highly unstable for fuel usage.

Nitrogen being a high calorific gas can also be used as a fuel but primarily its use has been confined to rocket propulsion systems. Liquid nitrogen is actively used as a fuel for space missions in rocket launchers. However owing to its high explosiveness and its tendency to emit large amount toxic of NOx emissions thereby increasing environmental pollution, it is not explored much as an engine fuel in automobiles.

India predominantly being an Agriculture based economy produces lots of crop waste every year, disposal of which is also a big concern. Also, with cow dung abundantly available in India, these waste food crops can be pulverized and mixed with cow dung and can be fed to a digestor for converting into gaseous fuel called Biogas and large quantities of manure. Biogas possesses high caloric value and has been used as a cooking fuel in past. Biogas is produced by the anaerobic decomposition of organic compounds and bio waste materials, Biogas contains mainly methane, Carbon dioxide, Nitrogen elements, Silicon oxide, Hydrogen sulphide and ammonia. The Biogas can be effectively used as engine fuel which can surely address two main issues the waste management and the pollution from engine emissions[16-17)].

This research work focusses on the usage of Biogas blended with other gaseous fuels as an engine fuel. It aims to assist in the proper disposal of bio waste and ensuring due energy security for the future generations by producing & using biogas as engine fuel in future. This can help in potentially reducing the crude oil imports and thus strengthening our economy. This work will be followed up by experimental investigation of proposed fuel blends for their emission and performance analysis. Finally an ideal gaseous blended fuel shall be recommended for use in engines as a sustainable and green fuel with minimal emissions.

2. Literature review

This section presents a brief summary of the potential gaseous fuels available across the globe, their usage as an engine fuel along with their relative advantages and disadvantages and the past research work done with these gaseous fuels up till now.

2.1 LPG as an alternate fuel

Some of the important past research done with LPG as fuel have given significant leads on its advantages.

Mustafa and Gitano-Briggs (2009) experimented with the usage of LPG as an alternate fuel for vehicle. When compared to gasoline, LPG was found to emit less carbon dioxide (CO_2) due to its low carbon content and high-octane rating. A single-cylinder, four-stroke engine with a displacement of 183cc and a compression ratio of 6.3:1 was used for the experimentation. Both gasoline and an LPG-gasoline blend were used to power it. A dynamometer was used to gauge performance. With the option of oxygen (O_2) and nitrogen oxides, an NDIR 5-gas analyser was utilised to examine a variety of exhaust products, including hydrocarbons (HC), carbon monoxide (CO), and carbon dioxide (CO_2) and oxides of Nitrogen (NO_x). The results showed that blended LPG-gasoline fuel increases brake-specific fuel consumption and brake thermal efficiency but decreases Brake power compared to pure gasoline fuel. About the emissions, apart from unburned HC, significantly lowered levels of CO, CO2, and NO_x were reported as LPG fraction was increased[10)].

Synak et al. (2019) examined the use of LPG as a substitute fuel for cars based on the pollutants it produces, the change in excise duty, and the difference in fuel use from the previous fuels. When LPG is delivered either in gaseous form or in liquid form, adjustments to both CI and SI engines are described. Furthermore, it is mentioned that using LPG is more cost-effective globally. When tests were completed again on the Dacia Sandero utilising both LPG and gasoline, high test performances were demonstrated for LPG. Due to its characteristics, which can seriously harm the engine and surroundings, LPG's limits as an alternative fuel were also examined[18)].

Kivevele et al. (2020) focuses on LPG-powered automobiles, which are produced utilising specialised LPG kits technology and are proving to be successful in current market trends. According to the World LPG Association's (WLPGA) annual report, there has been a surge for a number of reasons, including low operating costs, easy maintenance, environmental friendliness, and more. The many sorts of kit technologies are described along with methodologies for evaluating technological status and market trends[19)].

Mohammed et al. (2020) conducted an experiment to test LPG usage in SI engine and its effects on the environment. An SI engine that had been adapted to run on both gasoline and LPG was used in the experiment on a TD 200. The system included hydraulic dynamometers, a dual-fuel carburetor, an exhaust gas analysis equipment, and an engine test unit. The experiment was carried out using VDAS, and a number of performance characteristics, including fuel consumption, break fuel consumption, thermal efficiency, and volumetric efficiency, were analytically determined. Following the tests, it was discovered that using LPG in engine resulted in negative volumetric efficiency and better thermal efficiency, as well as lower brake fuel consumption and exhaust gas emissions[20)].

Grzelak and Taubert (2021) briefed about the LPG retrofit system and the pollutant emissions being exhausted from usage of the same. The only fuel used to start a vehicle with an LPG retrofit system is gasoline. The vehicle will therefore use fuel for a portion of its annual mileage. This article outlines the findings of experiments done on a car LPG retrofit system regarding how much gasoline is consumed when the engine is running on LPG, depending on the temperature. Tests were performed in a passenger car having a SI engine and modified with and LPG system, the measurements were done on the WLTC driving cycle. Although it was also seen that the gasoline injectors were only being used for a very small amount, the results revealed amazing mileage and lower pollutant emissions when the car was driving on LPG which was the major fuel throughout the driving test conditions[21)].

After examining numerous past research on LPG as a potential alternative fuel for use in vehicles, a few limitations were observed. Although LPG has far lower emissions and cost than gasoline, it has a number of significant disadvantages, including a high likelihood of engine catching fire and a pungent smell in the cabin and a performance decline. These are the reasons why LPG appears unsuitable for massive use in heavy vehicles particularly for everyday car operation.

2.2 CNG as an alternate fuel

CNG as fuel has higher calorific value as compared to LPG as shown in Table 1 and has many advantages.

Aslam et al. (2006) emphases on the minimisation of the emissions which are released into the atmosphere by the vehicles that run on gasoline. The work in this paper includes a comparative analysis of the performance as well as the emissions for CNG and gasoline. The methods used in this paper involve setup, retrofitting and comparison of test fuel properties. This research has shown that retrofitted CNG-fueled engines have the potential for higher FCE and significant reduction in the emissions. The limitations mentioned in this research manuscript in the weight of the CNG tank which causes a slight decrease in the efficiency of the engine[22)].

Bakar and Semin (2008) highlighted the use of compressed natural gas (CNG) as an alternate fuel for engines. This paper includes research and development in CNG to keep the power, torque, and emissions of natural gas engines comparable to gasoline or diesel counterparts. This research discusses the fuel characteristics of CNG and the development of CNG engines. Throughout the literature, there is consistent evidence that CNG has lower air pollution emissions and lower greenhouse emissions as compared to diesel and gasoline. When using natural gas engines, several major issues must be addressed, there is the set point for the optimal balance between emissions and economy is undetermined and the air-fuel ratio changes because of both operating conditions and fuel characteristics[23)].

Khan et al. (2015) focuses on the environmental as well as the economic aspects of compressed natural gas (CNG) as a transportation fuel. This research compares various aspects of CNG and natural gas such as economic aspect, emission performance and safety aspect. The technical aspects of compressed natural gas properties, storage, safety issues, and its impact on engine performance, efficiency, emissions, and barriers to natural gas vehicle adoption are carefully investigated. Throughout this review, the rising concerns about the adverse effects of the emissions caused by diesel and gasoline make CNG a very suitable fuel for transportation and can help in improvement of quality of air and social cost of ambient air pollution[24)].

Bielaczyc et al. (2016) presented an analysis of various emissions like Non-Methane Hydrocarbons (NMHC), Total Hydrocarbons (THC), CO, NO_x, and CO_2 during assessment of two bi-fuel vehicle that were filled with petrol and gaseous fuels. The aim of this paper was to study and examine the influence of gaseous fuels on exhaust emissions in comparison to those of gasoline-powered vehicles. Most of the conclusions were obtained and analysed on the outcomes obtained during the NEDC emissions test. CNG's good performance in terms of reduced particles and CO2 emissions confirms that it has significant potential as a transportation fuel[25)].

Sahoo and Srivastava (2021 compared the emissions of spark ignition (SI) engines operated on gasoline and Compressed Natural Gas (CNG). In this research, the impact of engine speed and compression ratio (CR) in variable compression port SI engine was also discussed in detail. The methodology includes experimental setup followed by various analysis such as knock analysis, performance analysis, combustion analysis and emission analysis performed under different engine speeds and high load operating conditions. Throughout the study it was witnessed that ISCO and ISHC emissions decreased with an increase in Compression Ratio (CR). Also, CNG showed lower ISCO, ISHC, and $ISCO_2$ emissions compared to gasoline. Further decline in emissions was observed using CNG at higher Compression Ratio[26)].

2.3 HCNG (Hydrogen + CNG) as an alternate fuel

Certainly, CNG has played an important role as an alternative gaseous fuel, but there was still room for improvement, as the above investigation and study clearly show that emissions were reduced when switching from other traditional fuels to CNG, but it wasn't the best possible engine performance scenario. On the other hand, the weight of the CNG tank was reducing engine efficiency and the stability of combustion was an issue that needed to be addressed in the case of CNG as a fuel. The forgone conclusion is that blending hydrogen into CNG improves the overall fuel quality. Because hydrogen has a high flame speed, combustion occurs more quickly, resulting in an improvement in low burning velocity and poor combustion stability of pure CNG.

Ma and Wang (2008) conducted an experimental study to investigate the various lean operation limits. A six-cylinder, throttle body injection, spark ignition engine was connected to an Eddy current dynamometer for load measurement and engine speed. Four different hydrogen blends of 0%, 10%, 30%, and 50% in volume were observed to have improved engine lean burn capability. At low load levels, increased engine speed helps to extend the lean operation limit, but not at high load levels[27)].

Xu et al. (2010) demonstrated in his work a comparative analysis of various aspects such as power, efficiency, emissions of a port injected spark ignited single cylinder engine using natural gas as fuel versus Hydrogen blends. Excess air ratio and spark timing effects were discussed. It was also discovered that increasing the proportion of hydrogen in blends causes a noticeable change in the peak cylinder pressure and maximum heat. the addition of hydrogen would result in drastic NO_x emissions, decreases unburned HC emissions and also a slight decrease in CO and CO_2 can be noticed. According to the study, proper ignition timing optimization with a lean mixture combustion could reduce NO_x emissions even if the blend contains up to 20% hydrogen. Hence can Improve thermal efficiency as well[28)].

Suryawanshi and Nitnaware (2011) conducted the research on HCNG blends in Spark ignition engines. They stated that pure CNG was a good alternative fuel option due to its low particulate and hydrocarbon emissions but It had a poor flame quality. As a result, % H2 in blend was proposed as a solution to the low burning velocity and poor combustion stability. In conclusion, Hydrogen requires a larger compressed storage tank volume than natural gas for the same energy requirements, and this HCNG blend in the lean burn range greatly improves combustion quality because Hydrogen produces more heat than methane per unit of oxygen consumed, while also lowering hydrocarbon emissions[29)].

Table 1. Calorific Values of Fuels

Fuel	Calorific Value (KJ/kg)
Gasoline	45,000
Ethanol	29,000
LPG	55,000
CNG	50,000
LNG	54,000
Biogas	45,000

Zareei and Rohani (2020) investigated the effects of various parameters such as ignition timing (IGT), injection timing (IT), and hydrogen volume fraction (H2%). The experimental setup included a four-cylinder spark ignition engine that was converted to computerintegrated CNGH fuel operation by installing a direct injection engine, and fuel was NG stored at 200 bar and H2 stored at 250 bar. The goal was to find an optimal blend of NG and H2 to maximise engine performance while lowering SFC and CO emissions. It was discovered that the optimal proportional value varies with speed. As a result, the entire study concluded that the engine works best when the proportion of H2 is between 20% and 30% in volume[30)].

Zareei, J. et al. (2021) investigated the effects of two-step fuel injection of hydrogen blending and natural gas on engine performance and exhaust emissions, using AVL software to examine fuel consumption, efficiency, exhaust emission, and so on. It was discovered that adding 30% HCNG resulted in 8%, 11%, and 13.6% increases in torque, engine power, and brake thermal efficiency, respectively. Because of the high flame speed, combustion occurs at a faster rate in the case of an HCNG blend, resulting in a high combustion chamber pressure. An important observation was that while the hydrocarbon and CO emissions were reduced by up to 14% at 2000 RPM when compared to CNG as fuel, the NOx emissions increased significantly with increase in Hydrogen and Speed of engine due to high temperature and Oxygen accumulation in combustion chamber[31)].

2.4 Methane + Hydrogen as alternate fuel

Hydrogen being a high calorific gas is blended in methane gas to increase its calorific value. This combination of methane and hydrogen has been experimented by some researchers.

Akansu et al. (2007) reported the effects of the use of mixture of methane and hydrogen in spark ignition engine. This research was carried out on a four-cylinder four stroke spark ignited Ford engine having a bore × stroke of 80.6 × 88 mm and a compression ratio of 10:1. The experiment was conducted in the engine laboratory in the department of Mechanical Engineering at the University of Ericeyes. The purpose of this study was to analyse the emissions and brake thermal efficiency (BTE) at 2000 rpm and constant load conditions. From the results, it was found that with the increase in percentage of H_2, the emission values of NO and brake thermal efficiency (BTE) increase whereas there is a reduction in emission values of HC, CO and CO_2. It was found a safe fuel with significant lower emissions. This research provides guidelines for developing and running internal combustion engines powered by natural gas (NG)-hydrogen mixtures. These results are also extremely important for operational adjustments required to optimise the hydrogen-powered SI engine design[32)].

Young-Kwang et al. (2011) investigated supported Potassium Carbonate for use in the inert and steam-reforming processes required for the catalytic conversion of lignite-derived tar into syngas. In order to catalytically transform tar compounds into syngas, first tar compounds must be adsorbed onto the catalyst surface following the release of volatile elements. Adsorbed tar compounds can be changed into hydrogen-rich syngas in this manner. Further which can be used as an alternative fuel for vehicles. Coke is created by the residual substances on the catalyst's surface[33)].

Acikgoz and Celik (2012) experimentally investigated the performance and emission characteristics of a hydrogen fuelled twin cylinder, four stroke, spark ignited (SI) engine. This research includes the modification of the engine followed by the various test procedures to determine the various engine parameters such as Brake specific fuel consumption (BSFC) and Brake Thermal Efficiency. It also includes the emission analysis of gases like CO, NO_X, HC and CO_2. The 100/0, 90/10, 80/20 and 70/30 CH4/H2 percentages mixtures were investigated in this study. It was concluded that, with addition of hydrogen to methane reduces HC, NO_X and CO_2 emissions. On the other hand, it was also found that, as hydrogen percentage in the mixture was increased, the BSFC values decreased. Furthermore, with increasing percentage of hydrogen, the brake thermal efficiency decreased[34)].

Karagoz et al. (2015) discusses about the engine performance i.e. brake thermal efficiency (BTE), brake specific fuel consumption (BSFC) and emission analysis of the exhaust gases like (CO, THC, smoke, and NOx). The tests were performed on a 4-stroke, water-cooled, naturally aspirated single cylinder compression ignition engine at a constant rpm of 1500, 100% engine load (the engine torque is fixed at 75.7 Nm), and different gas fuel energy levels (0%, 15%, 40%, and 75%). It was observed that, with increase in percentage of hydrogen in the fuel mixture, the brake thermal efficiency reduced whereas the levels of carbonmoxide and THC showed an uptrend as the gas fuel rate increased. A sigficant decrease in NO_x emissions was observed at medium energy content levels. Furthermore, when the energy content level was increased a sudden spike is NO_x was noted. Soot emissions decreased with an increase in the amount of hydrogen in mixture[35)].

Zhen et al. (2020) carried out an analysis on the combustion and emission performance of fuels such as methanol, ethanol and methane mixed with different ratios of hydrogen. This research includes the testing of fuel and the engine followed by the engine modelling and numerical modelling which was validated from the prior studies. In general, it was concluded that the time taken to start the engine and combustion duration was extended due to the addition of hydrogen in the fuel. As the mixture became more hydrogen rich it was noticed that emissions of NO_x and HC increased whereas CO and CO_2 emissions decreased. Methanol/hydrogen and methane/hydrogen blends emit less CO than ethanol/hydrogen blends. If hydrogen can be produced at a reasonable cost and there are good and safe ways to store and transport hydrogen in the future, it will promote the growth of energy and IC engines and reduce the environmental problems[36)].

Adrian et al. (2022) in his work discussed on how the eco-friendly nature of hydrogen makes it an ideal fuel for combustion. In this study, Ni, Cu, and B catalysts are combined to create transition metal-based catalysts supported by hydroxyapatite catalysts. Because Ni and Cu are relatively inexpensive compared to other transition metals, they were chosen as catalysts. Ni also works well as a solitary catalyst for the reaction that releases hydrogen from NaBH4. The use of Cu as a catalyst for this reaction has not been studied. The results showed that after the electrolysis process, hydrogen proved to be very effective as a combustible fuel[37)]

Makaryan et al. (2022) highlights the development done in the field of methane-hydrogen mixtures used as a promising low carbon fuel in various energy applications. This study gives us a detailed review on the energy characteristics of hydrogen as well as methane-hydrogen mixtures. From all the results, it was found that hydrogen and methane-hydrogen mixtures can be directly used as fuel for power plants as they provide high efficiency and good environmental performance. Also, it was clear from the results the hydroxy-methane blends when used in the internal combustion engines improve their performance and emission characteristics. This analysis shows that the risk of working with hydrogen is quite like that of methane. The research gaps in this manuscript include lack of proper knowledge to use the existing gas infrastructure to transport hydroxy methane mixtures. Serious studies are required on the compatibility of the pipeline materials with the fuel mixtures. It is necessary to provide proper storage and safe working environment for the operation of equipment with hydrogen and methane–hydrogen mixtures[38)].

2.5 LNG as alternate fuel

Liquified Natural Gas (LNG) is now considered to be the cleanest fuel. An increase in the global need for cleaner fuels has resulted in the demand for LNG as a fuel for vehicles as it has been proven highly clean and cheap in comparison to gasoline fuels. More and more developments are being made in this field to utilize LNG to fulfil all the needs. LNG is used currently in heavy vehicles as they have lesser idling timings and further research is going on to bring it in use for lighter vehicles.

Bassi et al. (2011) is talking in his paper about the use of LNG in road heavy vehicles. The work shows detailed view on the economic benefits of LPG as fuel, fuel energy density as an important feature for vehicles, LNG as fuel for heavy duty vehicles, simplified schema of a LNG tank installed on heavy duty road vehicle, simplified scheme of LNG and L-CNG filling stations, regulations on LNG and its standards. Additionally, it is suggested that the primary factor for heavy-duty natural gas vehicles is the increased energy density of LNG containers compared to diesel[39)].

Frigo and Gentili (2012) experimented and analysed the behaviour of a 4-stroke twin cylinder SI engine fuelled with ammonia-plus-hydrogen. This engine was specifically chosen and adapted for use in a range-extended car in which hydrogen is generated from ammonia using on-board catalytic reforming. The experimental results demonstrate that adding hydrogen to an air-ammonia mixture is required to improve ignition and boost combustion velocity, with ratios that rely mostly on load and less on engine speed. This research includes a series of setups and experimental procedures which were used to attain the necessary results. The results that were obtained were decrease in the exhaust pollutant emission and increase in stability of the engine by increasing hydrogen to ammonia energy ratio. The major disadvantage reported in this work was the decrease in the performance of the engine[40)].

Pfoser et al. (2018) in their work address the acceptance of LNG as an alternate fuel for vehicles using structural equation and technology acceptance models. In total 5 hypotheses were addressed where the needs and according to those needs the acceptance of LNG depended. The results showed that LNG as an alternative fuel can be promoted through raising demand, expanding LNG supply, and enhancing the fuel technology's environmental effects. Thus, making it highly acceptable for usage as an alternate fuel[41)].

Arefin et al. (2020) provided an overview of the potential and use of liquefied natural gas as a substitute fuel in diesel engines. This study explored the potential outcomes based on characteristics of LNG. It also focuses over the various challenges and the potential solutions for using LNG as a clean primary resource in the near future. Based on prior research, it was discovered that engine modifications, combined with optimal LNG consumption, improved system efficiency. It was also discovered that greenhouse gas emissions have been significantly reduced. Many recent researches have pointed high flammability, which can result in fatal hazards and knocking in dual fuel engines as key disadvantages of LNG[42)].

Kumar et al. (2021) provides an overview of the use of LNG as a future fuel, LNG characteristics, LNG imports from other nations, and its current global usage. It also includes a comparative analysis of natural gas production from various sources, as well as on the features of LNG, LPG, and CNG as automotive fuel. It was determined that, unlike other fuels, LNG is cleaner than other fossil fuels and gaseous fuels such as coal, oil, CNG, and methane, and that it is the most viable long-term choice. Climate change, escalating oil prices, decreasing LNG costs, increasing overall energy needs, fuel switching, the availability of natural gas from various offshore/onshore sites, the scope of utilisation of low-grade coal for LNG production, recovery of coal bed methane, and the availability of natural gas from biogas resources are the major factors contributing to the global growth of LNG. As a result, it is regarded as a safe and clean fuel for the future[43)].

2.6 Producer gas as alternate fuel

India has a lot of Coal and biomass-based solid fuels reserve, but their combustion, have been shown to emit a complex mixture of pollutants such as carbon monoxide, suspended particulate matter, formaldehyde, and others, posing a serious health risk, and causing serious lung diseases. On a sad note, the WHO has concluded that biomass-based solid fuel accounts for 75% of all premature deaths in children under the age of five. This reserve can be redirected towards biogas manufacturing[44]. Various past researchers have experimented with different types of biological waste materials like cow dung, waste part of the crops, spoiled vegetables and fruits, rice husk etc to produce producer gas or biogas. Even few researchers have experimented with using this producer gas as an engine fuel.

Rizk et al. (2007) noted that Fruit and Vegetable wastes (FVW) are produced in huge amounts around the globe and can be effectively used for generating biogas or producer gas. Authors experimented with the FVW, and added sewage sludge, reacting them in a 70-litre stainless steel anaerobic reactor for 105 days at room temperature (25- 30^{0}C). Tests were done based on pH level, water content, total alkalinity (TA), volatile fatty acids (VFA), total organic matter, ash content, organic content, chemical oxygen demand, volatile solids and phosphorous. Alkalinity, pH level, biogas volume were measured every day for the first 15 days and then after each week while the other factors were measured at a gap of 15 days throughout the experiment. The initial pH and the ratio of VFA/TA were not ideal. Water content of 88% and C/N ratio of 38/1 improved the digestion. 331 litters of biogas were generated in 105 days[45].

Ike (2010) proposed that Microorganisms can be used to produce biogas for a variety of feed stocks. Because there is such a wide variety of microbe species, it is impossible to standardize their reproduction, yield of desired chemicals, use, as well as their environmental needs and eating habits. For high-quality biogas output, distinct microbial groups must exactly interact, influenced by feedstock type and microbial inoculum. Methanobrevibacter and Methanosaeta are some of the micro-organisms used in cogeneration of biogas. Authors noted that Acetate, Hydrogen, and methyl compounds can all be used by Methanosarcina to produce methane[46].

Jha et al. (2015) noted that the vast unexplored potential for biogas production, upgrading and bottling. For using biogas like compressed natural gas for engine applications, biogas needs to be devoid of carbon dioxide, water particles, hydrogen sulphide and ammonia. Then the methane enriched gas was bottled at 200 bar pressure. An automated water scrubbing-based biogas purification plant was developed at IIT Delhi. This enriched gas was regularly used to fuel a Wagon-R car, and its emission testing was performed at ICAT. Emission results were found to comply perfectly with the Bharat stage-IV norms. The emission test showed that Biogas compared to CNG emitted 0.25 g/km less of CO, 0.21 g/km less of HC, 0.011 g/km less of NO_x emissions and 4.84g/km more of CO_2 emissions[47].

2.7 Biogas as alternate fuel

The Gas produced by the degradation of cow dung in a biodigester is called as Biogas and has the potential to be used as an engine fuel after compression. Compressed biogas can also be produced by a mixture of cow dung and other agricultural residues like crop waste, rice husk etc. Many researchers have explored the potential of biogas as fuel.

Jiang et al. (2003) carried out experiments on the dual fuel combustion ignition engine at Zhejiang Agricultural University. Authors investigated the various properties of compressed biogas (CBG), as well as the performance characteristics of CBG in the compression ignited dual fuel engine. Analyses and comparisons of high- and low-pressure biogas, utilised in the compression ignition dual-fuel engine was done to study the power variation and the related characteristic curve of the engine were produced using information drawn from experimental data acquired from the software. CBG burned satisfactorily in engine. The economic implications of using compressed biogas were also examined by authors[48].

Kapdi et al (2005) Authors concluded Biogas as a very clean engine fuel. Raw biogas contains about 55–65% methane (CH_4), 40% carbon dioxide, traces of hydrogen sulfide and water vapours. To make Biogas a transportable fuel, it needs to be compressed & filled in cylinders which is possible only after removing its CO_2, H_2S and water. Authors reviewed the efforts made to improve the quality of biogas by scrubbing CO_2 and the results obtained. Authors felt that there is a lot of potential if biogas could be made viable as a transport vehicle fuel like CNG by compressing it and filling into cylinders post scrubbing and proposed a unified approach for scrubbing, compressing and subsequent storage of biogas for wider applications[49].

Jiang et al. (2009) demonstrated the use of biogas as a fuel for vehicles by setting up two kinds of biogas engines which were biogas-diesel dual fuel engine and spark-ignition biogas generators. Authors conducted a few experiments for solving certain problems of low burning velocity, back burning, high exhaust temperature and severe heat in biogas engines. Based on the experiments Authors concluded compressed biogas to be a good fuel alternative with low cost & eco-friendly properties[50].

Chandra et al. (2011) converted a 5.9 kW diesel engine to spark ignition mode and used compressed natural gas (CNG) mixed with methane enriched biogas (Bio-CNG) and raw biogas. Engine performance was found best at 35° ignition advance. Loss of Power because of the engine conversion was found around 46%, 35% and 31% for raw biogas, methane enriched biogas and CNG, respectively. Methane enriched biogas exhibited nearly similar engine performance as that of CNG for Output power, thermal efficiency, and fuel consumption. The results concluded that methane enriched biogas is a good alternative for CNG, and it has neutral emissions of CO_2 to the atmosphere[51)].

Subramanian et al. (2012) conducted experiments to evaluate emissions and fuel economy of a vehicle equipped with a spark ignition engine fuelled with methane enriched biogas and CNG with the help of a chassis dynamometer. The results showed that the emissions of CO, HC and NO_x were less and met BS IV Emission Norms[52)].

Ray et al. (2013) used biogas derived from organic wastes and put it as fuel in CI engines. It was observed that light vehicles can run on biogas without modifications but heavy vehicles need certain modifications to run on biogas. Authors found water scrubbing as the easiest, most efficient, and least expensive method of methane enrichment. Also, an increased thermal efficiency was reported, by a CO reduction in biogas used for dual fuelling. The high heat release rate in the biogas HCCI mode is controlled by the presence of CO, therefore the engine parts longevity is unaffected. Thus, using biogas as an alternative fuel in C.I engines was recommended by the authors[53)].

Faria et al. (2017) performed simulation of a spark ignition engine fuelled with biogas using thermodynamic modelling of it. A thermodynamic equation was solved in the process. The results concluded that with certain modifications with the fuel it can deliver a good amount of performance, also the emissions were found to be significantly reduced[54)].

Khan et al. (2017) in their work investigated about upgrading engine for using biogas, the costs associated with it, how the gas can be utilised for maximum output, mixing of CNG with biogas to form Bio-CNG and how it can be stored for future usage[55)].

Sahota et al. (2018) discussed about sustainable bio energy development, biogas upgradation, bioenergy and uses of biomethane. Biomethane was found to be a promising renewable energy option and a suitable replacement of natural gas for fuel usage. Main advantage of upgraded biogas is the reduction in GHG emissions and ensures a healthier environment[56)].

Verma et al. (2019) investigated effect of compression ratio and EGR on the engine performance and emissions, by mixing diesel and biogas for use as fuel in dual fuel engines in their work. An engine with an initial CR of 17.5 and a 23 °BTDC injection timing, and a constant speed of 1500 rpm was selected for testing. The results concluded that the CR was increased significantly with high engine load resulting in higher thermal efficiency and the emissions were found reduced by nearly 18%, showing that biogas is eco-friendly[57)].

Sofia Dahlgren (2020) presented an overview of biogas-derived vehicle fuels, their technological maturity, and their potential as alternatives for fossil fuels in the transportation sector. It was observed that one thing they all have in common is that they are mostly made from fossil fuels. Only compressed and liquefied methane are economically generated from biogas. The greatest short-term promise is thus for greater usage of biogas as compressed and liquefied biomethane. It was concluded that the manufacture of fuels from biogas primarily follows two paths: either upgrading to biomethane and then compressing or liquefying it (CBG) or gasifying it to syngas for further fuel synthesis (LBG) (hydrogen, methanol, DME and FT diesel)[58)].

2.8 Propane gas as alternate fuel

Propane gas, one of the main components of the LPG and commonly used for cooking purposes, has also been tried by a few researchers in the past in engines because of its ultra-low exhaust emissions.

Fleming et al. (1972) used propane gas as a means of reducing pollution caused by engine exhaust. Results revealed that propane can be operated over a wider A/F ratio range with much lower carbon monoxide and hydrocarbon emissions compared to petrol. However, these were comparable to natural gas. Propane reported markedly lower emissions on retarding the ignition timing with lean A/F ratio however serious power loss was observed with propane[59)].

Straub et al. (2007) studied the variation of the constituents of LNG liquified natural gas on the gas turbine engine emissions. Authors reported that 5% increase in propane blending in the LNG supplied does not affects the NOx emissions from gas turbine exhaust. However, the air-fuel equivalence ratio and the adiabatic flame temperature does have a significant effect on NOx emissions. Overall propane blending was found to improve the combustion characteristics of the fuel[60)].

Kar et al. (2023) proposed propane gas as a potential substitute for heavy duty diesel engines due to its high knock resistance and CO_2 reduction potential. Authors studied the combustion behaviour of propane in an SI engine operated at lean air fuel and modelled its combustion characteristics and concluded that it has huge potential to reduce the end gas auto-ignition leading to engine knocking[61)].

2.9 Green Hydrogen gas as alternate fuel

One of the latest gaseous fuel candidate that has surfaced on the energy stage is Green Hydrogen. Researchers are seeing this as a fuel of future to ensure energy security to next generation.

Shadidi et al. (2021) found hydrogen to be an efficient and practical alternative engine fuel which can maximize fuel efficiency and appreciably lower exhaust gas emission. Because of the reduced pollutants by most engines, authors concluded that hydrogen fuel can be regarded as a clean and sustainable energy source. Authors investigated the impact of using hydrogen as a supplementary fuel for SI and CI engines on the engine emissions and performance. On using hydrogen as a fuel in the IC engines, the torque, power, and brake thermal efficiency was found to decrease, while the fuel consumption was found to increase. Results suggested that using hydrogen will reduce the emissions of sot, CO, UHC, and CO_2; however, NO_x are expected to increase[62)].

Santosa et al. (2013) investigated the utilization of hydrogen as a diesel engine fuel. Higher auto ignition temperature of hydrogen prohibits its direct use in diesel engine thus higher than that of diesel fuel thus authors used hydrogen in enrichment or induction. Authors investigated the combustion characteristics and indicated efficiency of this dual fuel engine. Hydrogen was introduced to the intake manifold using a mixer before entering the combustion chamber. The engine was tested at 2000 rpm and 10 Nm load. Hydrogen was introduced at the flow rate of 21.4, 36.2, and 49.6 liter/minute. The cylinder peak pressure and engine efficiency were found reduced at lower loads. The combustion rate was also found slower by the CFD calculation[63)].

Jamrozik et al. (2020) investigated a dual-fuel diesel engine, fueled by diesel fuel in the cylinder and hydrogen in the intake manifold. The affect of joint combustion of diesel and hydrogen fuel on the performance, stability, and emission was investigated. hydrogen proportion supplied was varied from 0 to 30%. Authors reported a 13% rise in combustion pressure on raising the hydrogen energy share to 30% whereas 35% rise in the heat release rate was reported. A significant decrease in engine stability was reported. The disadvantage of using hydrogen as a fuel for a compression-ignition engine was increase in HC emissions and a significant increase of 30% in NO emissions for 30% Hydrogen[64-66)].

3. Emission Behavior of various fuels

The effect of using various alternative fuels in the engine, on its exhaust emissions is discussed in this section.

Kudo, S. et al. (2012) worked on the catalytic processes used in the pyrolysis procedures to convert the biomass in a specific manner. Experiments were carried out using a quick catalytic procedure and the volatiles' capability for forming coke. It was discovered that catalysed pyrolysis of biomass offered benefits over other conversion techniques. Catalysed pyrolysis of biomass offers a significant deal of potential for utilisation[67)].

Jha, S. et al. (2018) investigated butanol-gasoline blends vs Ethanol-gasoline blends using a variable SI engine running at 1600 RPM with a compression ratio of 8 and various loads of 2.5, 5 and 7.5 Kg. The concentration of pollutants in emissions, specifically CO, CO_2, NO_x, and unburned HC, as well as engine performance for both blends, were the primary focus. CO and unburnt HC emissions were significantly reduced for both blends, as was brake specific fuel consumption, while NO_x emissions and brake thermal efficiency increased. Butanol has a greater negative impact on nitrogen oxide emissions than ethanol and butanol blends consume less brake specific fuel than ethanol blends[68)].

Pamitran et al. (2019) conducted an experimental study with a 3200 DWT passenger ship using 60% LNG as fuel. Various analyses were carried out, including energy transfer rate and tank wall destruction due to heat transfer. It was discovered that the energy destruction rate has a positive relationship with the boil off rate (BOR) and the boil off gas (BOG) values. The lower the value of BOR, the greater the value of heat leak through the tank wall and the greater the value of exergy removed and destroyed. The lower the value of Rtot, the better the thermal insulation capability of a system, and thus the higher the value of exergetic efficiency[69)].

Jha and Singh (2021) conducted a study to investigate the effect of combining bio diesel and alcohol in various proportions, and different parameters such as compression ratio and loads were varied for each blend. It was discovered that all blends showed a reduction in CO-based emissions and an increase in CO2 emissions when the load was increased, indicating complete combustion, but NOx emissions were significantly increased when the load was increased because of high adiabatic flame temperature of gases inside the cylinder[70)].

Kurnianto et al. (2022) talk about gasification of bio-wastes which further would be used as an alternative fuel for engine generators or gas burners. An Internet of Things (IOT) based system was designed to monitor all the stats and data and process it further to an android device. A downdraft gasifier (fixed bed) was used for the experimentation purpose. After the results it was seen that Future designs of IoT-based systems will increase accuracy and delay, and they will be evaluated in rural settings in a natural context[71)].

Kouzelis et al. (2022) developed a decision-making tool by combining the overall performance of alternative fuels based on technological, environmental, and other criteria with a financial model based on discounted cash flow analysis. This allows us to find the best alternative fuel by maximising performance on technological and environmental criteria while minimising the desired freight rate obtained by optimising for economic vessel speed. According to the findings, upgraded bio-oil, Fischer-Tropsch diesel, and liquefied biomethane are the best future alternative maritime fuels[72-75)].

Bizhanova et al. (2022) observed that economic development of any country must be environmentally safe, demonstrating the importance of sustainable development. The author chose Kazakhstan legislation as a case study, and it was understood that advancements must also focus on making the environment safe and free of emissions, and automotive vehicles emit a very large portion of this pollution, causing environmental damage. However, stopping the use of these conventional fuel-based engines is not the solution because it would be a total waste of all those engines. As a result, biogas can be regarded as the automotive industry's future, as it can be used in all of those engines with minimal modification and can serve as a long-term solution to this massive problem[76)].

Bhasin et al. (2015) carried out a case study on thirty different businesses in India to learn about the measures they took to reduce pollutants in their emissions in their annual reports. Increasing steadily Greenhouse gases endanger our environment, but using sustainable products and services can only mitigate the risk. It was discovered that businesses in the automobile and IT sectors received a commendable score on the spectrum of environmental disclosure index. The environmental disclosure index can be calculated using content analysis to convert qualitative information found in the annual reports of these 30 companies in the pursuit of a low-carbon economy into quantitative information[77-78)].

4. Conclusions and future scope

Following conclusions can be safely drawn from the above review work done in the domain of the various alternative fuels used to compensate the petroleum-based fuels and minimise pollution:

- In general, gaseous fuel are way more cleaner than liquid fuels like gasoline as they give out much lesser emissions wrt the petroleum based pure gasoline fuel.
- Reduced calorific value of gaseous fuels leads to significant drop in engine performance and their storage consumes significant volume of the boot space.
- High caloric value gases like Hydrogen, Nitogen or biogas can be blended in CNG in very modest quantities (upto 5%) to boost engine performance an reduce storage requirements. However, this approach needs further deliberations for firm conclusion.
- These gaseous fuels can be safely used to substitute coal in power plants thus leading to cleaner power production and minimisation of environmental pollution. The retrofitting of power plant burners needs to be further deliberated upon.
- Alcohols such as Ethanol, methanol have properties very similar to gasoline and be mixed in moderate quantities (upto 20%) in gasoline. Alcohol blended fuels give much lesser emissions compared to gasoline however there is a little drop in engine performance.

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