Alternative Fuels for Internal Combustion Engines: Overview of current research

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Abstract

The world is facing a huge problem of high fuel prices, air pollution and a lot of climatic changes. Alternate Fuels play an essential role in the present scenario in Internal Combustion Engines as the mineral fuels are depleting. This paper presents the maneuver and origin of the use of alternative fuels in internal combustion ignition engines. Analysing the literature, this article shows various alternative fuels utilized in India and all over the world. Furthermore, this article describes the research directions for alternative fuels usage in road transport powered by internal combustion engines.

Keywords — *Alternative fuels, bio fuels, diesel engine, eco-fuels.*

I. INTRODUCTION

The increasing motorisation of the earth has led to a steep rise in the demand of petroleum products. But petroleum resources are :

- Finite
- Highly concentrated in certain provinces of the world
- Source of environmental pollution.

The transportation sector consumes 65 percent of the total petroleum products supplied. In India, the transportation sector contributes:

- around 1/3rd of CO2 emissions
- around 1/3rd of NOx emissions
- almost 77 % of CO emissions
- around 45 % of particulate matter (PM)

A growing number of people believe alternative fuels will have an expanded role in the cars and trucks of tomorrow. According to Larry West, such interest has been spurred by three essential considerations:

- Alternative fuels generally have lower vehicle emissions that contribute to smog, air pollution and global warming.
- Most alternative fuels don't come from finite fossil-fuel resources and are sustainable.
- Alternative fuels can help nations become more energy independent.

With this in mind, it is observed that the U.S. Energy Policy Act of 1992 identified eight alternative fuels of note – some that are used, others considered more experimental in kind. Alternative fuels, known as non-conventional and advanced fuels , are any materials or substances that can be used as fuels, other than conventional fuels like; fossil fuels (petroleum (oil), coal, and natural gas), as well as nuclear materials such as uranium and thorium, as well as artificial radioisotope fuels that are made in nuclear reactors.

Some well-known alternative fuels include biodiesel, bioalcohol (methanol, E1510, butanol), refuse-derived fuel, chemically stored electricity (batteries and fuel cells), hydrogen, non-fossil methane, non-fossil natural gas, vegetable oil, propane and other biomass sources. To reduce reliance on petroleum-based fuels, Alternate fuels are the best solution for the tomorrow IC engines. "Alternative fuel" means fuel that is

- For use in motor vehicles to deliver direct propulsion,
- Less damaging to the environment than conventional fuels, and
- Prescribed by regulation, including, without limiting the generality of the foregoing, methanol, propane gas, natural gas, ethanol, hydrogen or electricity when used as a sole source of direct propulsion energy.

II. METHANOL AND ETHANOL (ALCOHOL FUELS)

A. *Methanol:*

Methanol is an alcohol fuel. The primary alternative methanol fuel being used is M-85, which is made up of 85 percent methanol and 15 percent gasoline. In the futurition, neat methanol (M-100), may also be used.

Methanol is mainly produced from natural gas. Coal and cellulose consisting biomass like wood etc. may also be used to produce methanol. Methanol (CH_3OH) is an alcohol fuel. Methanol is methane with one hydrogen molecule replaced by a hydroxyl radical (OH). The alternative fuel currently being used is M-*%. In the future, neat methanol or M-100 may also be used. Methanol is also made into ether, MTBE, which is blended with gasoline to enhance octane and to create oxygenated gasoline. Methanol confines no sulphur or complex organic species.

1) *Production of Methanol:*

Methanol is created from a synthesis gas (hydrogen and CO), which is reacted in the presence of a catalyst. Methanol can also be manufacture from non-petroleum feed-stocks such as coal and biomass. Methanol can be produced from a verity of feedstock, including natural gas, coal, biomass and cellulose. It is predominantly produced by steam reforming of natural gas to create a synthesis gas, which is then fed into a reactor vessel in the presence of a catalyst to produce methanol and water vapour. In fact today's economics favour its production from natural gas.

2) *Environmental Characteristics:*

Emissions from M-85 vehicles are somewhat lower than in gasoline powered vehicles. Smog-forming emissions are collectively 30-50 percent lower; NOx and hydrocarbons emissions from M-85 vehicles are similar to slightly lower. However, CO emissions are by and large equal or slightly higher than in gasoline vehicles.

3) *Emissions:*

Methanol perhaps is not the cleanest gasoline alternatives but it has a distinct advantage in controlling ozone formation. USA is centred to methyl alcohol and methanol blends as it promises significant ozone improvements and control smog formation at a reasonable detriment.

The following table (Table-1) gives emissions comparison between gasoline, M85 and M100.

Table-1: Emissions form gasoline, M85 and M100 in a FTP Cycle

Emissions, mg/km FTP cycle	**Gasoline**	**M85**	**M100**
THC	161.59	111.87	124.30
CO	733.37	683.65	870.11
NOx	490.99	379.12	285.89
Evaporative emission (mg/test) FTP test	1720.00	680.00	880.00
Benzene	7.79	4.38	0.32
Toluene	33.66	8.66	2.11
Buta-1-3-diene	0.19-0.50	0.44	2.05
Formaldehyde	4.78	13.87	21.76
Acetaldehyde	0.94	10.02	0.27

4) *Advantages:*

- High octane and performance characteristics.
- Only smaller modifications are needed to allow gasoline engines to use methanol.
- There is a significant decrease of reactive emissions when using M-85.

5) *Operation & Performance:*

- Because of low energy content, mileage will be slightly lower.
- Power, acceleration and payload are comparable to those of equivalent internal combustion engines.
- Methanol needs special lubricants.
- Compatible replacement parts are required.

Methanol is mostly used in light-duty vehicles. More than 20,000 M85 flexible-fuel vehicles are in operation in USA.

B. *Ethanol:*

Ethanol is a cheap non-petroleum based fuel. As with methanol, E-85 is the primary ethanol alternative fuel. The use of ethanol in vehicles is not a new innovation. In the 1880s, Henry Ford built one of his first automobiles to run on ethanol. Ethanol (ethyl alcohol, grain alcohol, EtOH) is a clear, colourless liquid with a characteristic, agreeable odour. In dilute aqueous solution, it has a somewhat sweet flavour, but in more concentrated solutions it has a burning taste. Ethanol (CH_3CH_2OH) is a group of chemical compounds whose molecule contains a hydroxyl group, -OH, bonded to a carbon atom. Ethanol made from cellulosic biomass materials instead of traditional feedstock (starch crops) is called bio ethanol.

The Clean Air Amendments of 1990 mandated the sale of oxygenated fuels in areas with unhealthy levels of carbon monoxide. Since that time, there has been strong demand for ethanol as an oxygenated blended with gasoline. In the United States each year, more than 1.5 billion gallons are added to gasoline to increase octane and improve the emission quality of gasoline. In some areas ethanol is blended with gasoline to form an E10 blend (10% ethanol and 90% gasoline), but it can be used in higher concentrations such as E85 or in its pure form.

Ethanol is produced almost entirely from the renewable sources from fermentation of carbohydrate containing biomass like sugar, grains, tapioca etc. Neat ethanol (95% ethanol + 5% water) and anhydrous ethanol blended up to 20% in Gasoline have been widely used in Brazil during 1980s. In the USA, use of ethanol initially started in the agricultural surplus states like Nebraska for blending in the reformulated Gasoline as oxygenate. Now, ethanol is the preferred oxygenate replacing methyl tertiary butyl ether (MTBE). The 10% ethanol-Gasoline blends used in the USA are commonly referred as 'Gasohol'. Germany, Sweden, New Zealand and California focused mainly on methanol as an automotive fuel due to its potential near the natural gas field and it being liquid can be more easily handled and transported compared to natural gas.

*1) **Production of Ethanol:***

It can be produced by fermentation of vegetables and plant materials. In India, its main source is molasses - a by-product of sugarcane. It's done in three stages

1. Extraction of juice from sugarcane
2. Fermentation of the juice
3. Distillation

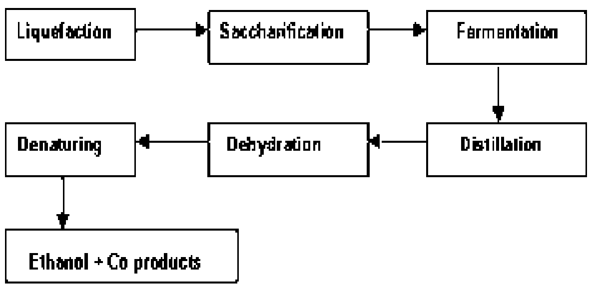

Fig 1: Production of ethanol

Fuel ethanol is denatured with small amount (2%-5%) of some product such as gasoline, to make it disqualify for human consumption. Two principal co products of ethanol production are CO_2 and distillers grain. Many ethanols collect the CO_2, clean it of any residual alcohol, constrict it and sell it for use in carbonate beverages or to flash freeze meat.

*2) **Environmental Characteristics***

It has approximately 30-50% fewer smog forming emissions than a gasoline vehicle. Air toxics are also reduced by about 50 percent when compared to gasoline. As with all internal combustion engines, vehicles using ethanol emit minor amounts of aldehydes. This is resolved by installing advanced catalytic converters on the vehicles.

Major problem with ethanol is the corrosion. Ethanol driven vehicles require lines, hoses and valves to be resistant to the corrosion that alcohol can induce. Alcohol corrodes lead-plated fuel tanks; magnesium, copper, lead, zinc, and aluminium parts; and some synthetic gaskets.

*3) **Emissions Characteristics:***

Emission results of a test conducted by National Renewable Energy Laboratory (NREL), USA are given in the following table. The test was conducted on Taurus 1998 model with both E85 and gasoline RF-A (industry average gasoline). Table-2 shows the comparative emissions from ethanol and gasoline fuelled vehicle.

Table-2: Comparative Emissions (Ethanol vs. Gasoline)

Emissions in g/mi	AFV-Ethanol	Gasoline
NHMC	0.10	0.10
CO	1.48	1.13
NO_x	0.12	0.09
CO_2	396.4	439.7

Emissions of total potency weighted toxics (including benzene, 1-3, butadiene, formaldehyde, and acetaldehyde) for the E85 were 55% lower than that tested on gasoline.

A recent Australian study with E10 gives the following emission results:

- Decreased emissions of CO by 32%.
- Decreased emissions of HC by 12%.
- Decrease in non-regulated toxics: 1-3 butadiene decrease by 19%, benzene decrease by 27%, toluene decrease by 30% and xylene decrease by 27%.
- Increase in non-regulated toxics: acetaldehyde increase by 180% and formaldehyde increase by 25%.
- 1% increase in NO_x

Recent Australian life-cycle analysis work has revealed that E10 blends are considered greenhouse neutral. The same study revealed that E10 decreased tail pipe emissions of hydrocarbons and NO_x (25% and 15% respectively), but particulates (PM10) remained unchanged.

III.NATURAL GAS - LNG & CNG

Natural gas is a mixture of hydrocarbons-mainly methane (CH_4) and is produced either from gas wells or in conjunction with crude oil production. Due to its low energy density for use as a vehicular fuel, it is compressed to a pressure of 200-250 bars to facilitate storage in cylinders mounted in vehicle and so it is called compressed natural gas (CNG).

India's recoverable resources of more than 690 billion cubic meters make it a long-term substituted fuel for use in petrol and diesel engines. Low noise, low exhaust emissions, less maintenance, not prone to adulteration, driver's comfort, etc. are some of the attractive features of CNG as an automotive fuel. It can be stored on a vehicle either in a compressed gaseous state (CNG) or in a liquefied state (LNG).

The principal constituent of natural gas is methane (80 to 95% by volume). The balance is composed of small and varying amounts of other hydrocarbons such as ethane, propane, butane and heavier hydrocarbons and non – hydrocarbon gases carbon dioxide, nitrogen, water, hydrogen sulphide and other trace gases. Typical composition is given in Table 3. The natural gas before transportation or use is upgraded by removing water, hydrogen sulphide and condensable higher hydrocarbons. It helps in prevention of condensation of these compounds in pipeline and also valuable by-products are obtained. Natural gas, once flared-off as an un-needed byproduct of petroleum production, is now considered a very valuable resource.

Table-3 Composition of CNG.

Constituents	% Volume
Methane	93.20
Ethane	04.27
Propane	01.38
i-Butane	00.18
n-Butane	00.20
i-Pentane	00.04
n-pentane	00.03
Carbon dioxide	00.27
Nitrogen	00.43
Moisture content	2.0 ppm

A. Production:

Natural gas is mainly extracted from gas wells or in conjunction with crude oil production; it can also be produced as a "by-product" of landfill operations. Natural gas can be produced domestically. Gas streams produced from reservoirs or wells contain natural gas liquids and other materials. Processing is required to separate the gas from petroleum liquids and to remove contaminants. First the gas is separated from free liquids such as crude oil, hydrocarbon condensate, water and entrained solids. The separated gas is further processed to meet specified requirements. Natural gas when stored and distributed in the liquid phase is called Liquefied Natural Gas or LNG. LNG essentially facilitates storage and transportation of natural gas. This LNG is again reheated to CNG and filled on-board a vehicle for use as fuel. Vehicles running on LNG are also available in many parts of the world.

B. Environmental Characteristics:

Natural gas has low CO emissions, virtually no PM (particulate matter) emissions, and reduced volatile organic compounds. Per unit of energy, natural gas contains less carbon than any other fossil fuel, leading to lower CO_2 emissions per vehicle mile travelled.

C. Advantages

1. It is cheap
2. It is Engine-Friendly
3. It is safe
4. There is lot of it in India.
5. It's clean, easy to trap and odourless.

D. Disadvantages

1. The storage cylinder takes a lot of space.
2. CNG gas stations are not widely available in India.

E. Emissions:

Given the availability and the infrastructure, CNG qualifies to be one of the most prominent alternative fuels. It stands substantially better than conventional fuels both in life cycle emissions and vehicle exhaust emissions. Table-4 gives the comparative emissions from CNG and conventional diesel. Emission results as tested by the Indian manufacturers are given in Table-5, 6, 7and 8.

Table-4: Comparative Emissions from CNG & Diesel

Fuel	Emissions in g/km				PM emissions relative to CNG
	CO	NMVOC	NOx	PM	
Low Sulphur diesel (500 ppm)	1.32	0.50	14.72	0.22	340% higher
ULSD (50 ppm)	1.41	0.52	14.32	0.16	220% higher
CNG	0.66	2.75	9.87	0.05	-

Source: Tom Beer et al 2000, Lifecycle emission analysis of alternate fuels CSIRO report to Australian Greenhouse Office March, mimeo

Table-5 Emission Results for Bajaj Three – Wheelers

Type	CO	THC	NMHC	No_x
2-stroke (Petrol RE)	0.29	1.45	-	0.1
2-stroke (CNG RE)	0.8	5.74	0.291	0.02
4-stroke (Petrol RE)	0.45	0.68	-	0.56
4-stroke (CNG RE)	0.29	2.4	0.17	0.75

Table–6 Bus (TELCO) Emission results – Euro – II Diesel Vs CNG

Emissions(g/kWH)	Diesel (Euro – II + Cat.con)	CNG with Cat.con
Carbon monoxide	1.06	1.68
Total Hydrocarbons	0.36	1.64
Nitrogen oxides	5.89	3.42
Particulates	0.113	0.03

Table–7 Emission results for Ashok Leyland Diesel buses

	Test results (gms/kWH)

Pollutant	Diesel	CNG
Oxides of Nitrogen	3.24	7.721
Carbon monoxide	3.12	1.820
Hydrocarbons	1.30	0.262
Non-methane hydrocarbons	0.04	-
Particulate matter	0.014	0.31

Table–8 Type approval CNG mass emissions for converted engines

Manufac turer	Year of Mfg.	Capacity (Ltr)	Emission in gms/kWH			
			CO	THC	NM HC	NO_x
TELCO	1993	5.721	1.8	3.04	0.41	5.9
TELCO	1993	5.721	2.5	3.08	0.41	5.1
TELCO	1996	6.675	0.4	2.97	0.50	10.8
ASHOK LEYLAND	2000	6.014	1.3	2.60	0.35	5.8
TELCO	1996	5.675	5.5	1.37	0.18	14.1
ASHOK LEYLAND	1992	6.075	9.3	5.09	0.70	12.0

IV. LIQUEFIED PETROLEUM GAS – LPG

LPG is a by-product of natural gas processing or a product that comes from crude oil refining and is composed primarily of propane and butane with smaller amounts of propylene and butylenes. Since LPG is largely propane, the characteristics of propane sometimes are taken as a close approximation to those of LPG. Composition of LPG and CNG is given in Table-9.

Table-9: Composition of LPG & CNG

% composition	CNG	LPG
Methane	84.50	-
Ethane	7.70	0.2
Propane	2.40	57.3
Butane	0.58	41.1
Pentane	0.37	1.4

Liquefied petroleum gas (LPG) consists of various hydrocarbons, mainly propane, propylene, butane, and butylene in various mixtures. The main constituent, in most of the cases, is propane.

A. Production:

LPG is a by-product of natural gas processing and petroleum refining. LPG is a by-product of two sources: natural gas processing and crude oil refining. When natural gas is produced, it contains methane and other light hydrocarbons that are separated in a gas processing plant. Because propane boils at -44 degrees F and ethane boils at -127 degrees F, separation from methane is accomplished by combining increasing pressure and decreasing temperature. The natural gas liquid components recovered during processing include ethane, propane and butane and other heavier hydrocarbons. Propane and butane along with other gases are also produced during crude refining as a by-product of the process that rearrange or break down the molecular structure to obtain more desirable petroleum compounds.

Oil wells are primary source and refineries are a secondary source of natural gas where the dissolved gases in the Petroleum crude are released during the refining process, but in lesser volumes. CNG is a safe fuel. Being lighter than air, it diffuses easily into the atmosphere and does not form a sufficiently rich mixture for combustion to take place. In this respect, CNG is superior to other fuel. Storage of propane on vehicles is not as cumbersome as CNG, but the cost of propane is higher than that of CNG. CNG represents a more cost effective emission reduction measure than quite a few other options that have been the subject of serious debate in recent years.

B. Environmental Characteristics:

The LPG run vehicles have lower emission of reactive hydrocarbons (about one-third less), NOx (20 percent less), and CO (60 percent less) than gasoline vehicles.

C. Emissions:

The main constituent of LPG is propane. Lower carbon-to-hydrogen ratio, higher octane rating and its ability to form a homogeneous mixture inside the combustion chamber enable it to produce lesser emissions compared to conventional fuels. Table-9 gives a comparative emissions status from Euro-II diesel and LPG buses. LPG outperforms conventional fuels in both regulated and non-regulated emissions. Comparison of non-regulated components of emissions between diesel and LPG vehicles is given in Table-10. Non-regulated components of emissions like aldehydes and poly-aromatic hydrocarbons are much lower from CNG vehicles compared to that of diesel vehicles.

Table-10: Comparative Emissions from Euro-II Diesel & LPG Bus

Pollutants	Euro-II Diesel+ ULS/CRT	LPG	% Change
HC(g/km)	0.143	0.027	-81%
CO(g/km)	0.212	0.013	-94%
NO_x/10(g/km)	1.254	0.54	-57%
Particulates (g/km)	0.028	0.017	-39%
CO_2/1000 (g/km)	1.344	1.309	-4%

Source: Millebrook-ref:9

Table- 11: Comparison of non-regulated Emission (Diesel Vs LPG)

Emission Component	Euro-II Diesel Bus	LPG Bus
Toxic effects(%) PAH BTX Lower Aldehydes	 100 100 100	 <15%–35% 20-40%
Summer Smog Potential(Ethane equivalent) (%)	100	40%
Acidification (%)	100	20-50%
Winter Smog Potential (%)	100	<15 %

Source: The Alternative Fuels Directory- TNO, 1998

D. Advantages of LPG:

1. Its cost is 60% of petrol with 90% of its mileage.
2. Has a higher octane number and burns more efficiently.
3. LPG has many of the storage and transportation advantages of liquids, along with the fuel advantages of gases.
4. Saves on the maintenance costs.

E. Disadvantages of LPG:

Many countries in the world are using LPG as automotive fuel. Many years of experience of successful use of LPG in vehicles and the emission benefits it offers really support it to outperform the associated disadvantages of the fuel, if any. Moreover, familiarity with LPG in household application like cooking makes it more acceptable to the users. However, in the initial stages of introduction of this fuel, issues like safety, storage & handling, extreme volatility of the fuel, etc. needs proper attention.

V. HYDROGEN (H_2)

Hydrogen (H_2), when used in a fuel cell to produce electricity is an emissions-free alternative fuel produced from diverse energy sources. Through retail dispensers, it fills passenger vehicles in less than 10 minutes to provide a driving range of more than 300 miles. Research and commercial efforts are under way to expand the hydrogen fuelling infrastructure and production of fuel cell electric vehicles

A. Production

Hydrogen can be produced from a number of different sources, including natural gas, water, methanol etc. Two methods are generally used to produce hydrogen:
(1) Electrolysis
(2) Synthesis gas production from steam reforming or partial oxidation.

Hydrogen on combustion produces water and there are no emissions of carbon containing pollutants such as HC, CO and CO_2 and air toxics benzene, PAH, 1-3 butadiene and aldehydes. Trace amounts of HC, CO, and CO_2 originating from burning of lubricating oil however, may be emitted. NO_x is the only pollutant of concern from hydrogen engines. Very low NO_x emissions are obtained with extremely lean engine operation ($\varphi<0.05$) [70]. Injection of water into intake manifold or exhaust gas recirculation which in this case consists primarily water vapour, can further suppress formation of nitrogen oxides. In addition, water injection provides charge cooling and control of pre-ignition and backfiring in the engines using external mixture preparation. The direct fuel injection in the cylinder mitigates some of the problems faced by the engines with external mixture preparation.

Hydrogen fuelled engines produces almost no CO_2 and its global warming potential is insignificant. Considering the total well-to-wheel energy analysis however, when hydrogen is produced from fossil resources hydrogen fuelled vehicles provide no overall reduction in greenhouse gas emissions and in some cases even worse than the vehicles fuelled by the conventional Gasoline and diesel fuels.

Also the addition of H_2 to other traditional slower burning fuels with narrow operational mixture range such as those of methane and bio-gases, can accelerate significantly the flame propagation rates, extend greatly the lean operational mixture range while reducing the emissions of CO_2 .

B. Environmental Characteristics

When combusted (oxidized), only water vapour is produced. When burned in an internal combustion engine, small amounts of nitrogen oxides and small amounts of unburned hydrocarbons and carbon monoxide are produced, due to the use of engine lubricants.

C. Advantages

- Hydrogen-air mixture burns nearly 10 times faster than gasoline-air mixture.
- Hydrogen has high self-ignition temperature but requires very little energy to ignite it.
- Clean exhaust, produces no CO_2.
- As a fuel it is very efficient as there are no losses associated with throttling.

D. Disadvantages

- There is danger of back fire and induction ignition.
- Though low in exhaust, it produces toxic NO_x.
- It is difficult to handle and store, requiring high capital and running cost.

VI. BIODIESEL

Biodiesel (mono alkyl esters) is a cleaner-burning diesel fuel made from natural, renewable sources such as vegetable oils. Biodiesel operates in compression ignition engines like petroleum diesel thereby requiring no essential engine modifications.

Moreover it can maintain the payload capacity and range of conventional diesel. Biodiesel fuel can be made from new or used vegetable oils and animal fats.

Biodiesel is a renewable fuel that is produced from a variety of edible and nonedible vegetable oils and animal fats. The term "biodiesel" is commonly used for methyl or ethyl esters of the fatty acids in natural oils and fats that meet the specifications for their use in the CI engines. Straight vegetable oils are not considered as biodiesel although attempts have been made to use these as well in the CI engine. Biodiesel is typically produced by a reaction of vegetable oils or animal fats with an alcohol such as methanol or ethanol in the presence of a catalyst to yield mono-alkyl esters. Glycerin is obtained as a by-product, which is removed. The straight mineral oils have very high viscosity that makes flow of fuel difficult even at room temperatures and presence of glycerin in the vegetable oil causes formation of heavy carbon deposits on the injector nozzle holes.

A variety of vegetable oils such as those from soybean, rapeseed, sunflower, jatropha – carcass, palm, and cottonseed etc. have been widely investigated for production of biodiesel. Rapeseed oil and some other vegetable oils when transformed to their methyl esters have many characteristics such as density, viscosity, energy content, and cetane number close to that of diesel. The more widely used are Rapeseed Methyl Ester (RME) in Europe and Soybean Methyl Esters (SME) in the US. They are collectively known as Fatty Acid Methyl Esters (FAME). Recently non-edible oil produced from jatropha-curcass seeds has gained interest as this plant can be easily grown on wastelands.

The vegetable oil esters are practically free of sulphur and have a high cetane number generally in the range 46 to 60 depending upon the feedstock. The cetane number of methyl esters tends to be slightly lower than of ethyl or higher esters [54]. Biodiesel from saturated feed stocks such as animal fat and recycled restaurant cooking fats will generally have a higher cetane number than the esters of oils high in poly-unsaturates such as soybean oil. Due to presence of oxygen, biodiesel have a lower calorific value than the diesel fuels.

Biodiesel is a fuel made primarily from the oils and fats of plants. Although, it can be used as a straight replacement to diesel, the blend of biodiesel to diesel can be as low as 20% biodiesel, 80% diesel.

Production: Biodiesel can be produced through a transesterfication process, forming fatty esters. One of the by-products of production is glycerol, which can then be sold as an independent product.

Biodiesel is the only alternative fuel to have a complete evaluation of emission results and potential health effects submitted to the U.S.EPA under the Clean Air Act Section 211(b). Comparision of emissions from biodiesel and petrodiesel is given in Table-12.

Table-12 Comparision of emissions from biodiesel and petrodiesel

Emissions	B100	B20
Regulated Emissions		
Total Unburned Hydrocarbons	-93%	-30%
Carbon Monoxide	-50%	-20%
Particulate Matter	-30%	-22%
NOx	-13%	+2%
Non-Regulated Emissions		
Sulphates	-100%	-20%
Polyciclic Aromatic Hydrocarbons (PAH)**	-80%	-13%
NPAH (Nitrated PAHs)**	-90%	-50%***
Ozone Potential of Speciated HC	-50%	-10%
Life-Cycle Emissions		
Carbon Dioxide (LCA)	-80%	

*Estimated from B100 results. **Average reduction across all compounds measured.
***2-nitroflourine results were within test method variability.

A. Advantages of biodiesel:

The benefits of biodiesel are:

- The lifecycle production and use of biodiesel produces approximately 80% less carbon dioxide emissions, and almost 100% less sulphur dioxide. Combustion of biodiesel alone produces over a 90% reduction in total unburned hydrocarbons, and a 75-90% reduction in aromatic hydrocarbons. Biodiesel further provides significant reductions in particulates and carbon monoxide than conventional diesel fuel.

- Biodiesel is the only alternative fuel that runs in any conventional, unmodified diesel engine.
- Needs no change in refueling infrastructures and spare part inventories.
- Maintains the payload capacity and range of conventional diesel engines.
- Diesel skilled mechanics can easily attend to biodiesel engines.
- 100% domestic fuel.
- Neat biodiesel fuel is non-toxic and biodegradable. Based on Ames Mutagenicity tests, biodiesel provides a 90% reduction in cancer risks.
- Cetane number is significantly higher than that of conventional diesel fuel.

- Lubricity is improved over that of conventional diesel fuel.
- Has a high flash point of about 300 F compared to that of conventional diesel, which has a flash point of 125 F.

B. *Disadvantages of biodiesel:*

Some of the disadvantages of biodiesel are:

- Quality of biodiesel depends on the blend thus quality can be tampered.
- Biodiesel has excellent solvent properties. Any deposits in the filters and in the delivery systems may be dissolved by biodiesel and result in need for replacement of the filters.
- There may be problems of winter operatibility.
- Spills of biodiesel can decolorize any painted surface if left for long.
- Neat biodiesel demands compatible elastomers (hoses, guskets, etc.).

C. *Environmental Characteristics:*

Biodiesel has no aromatic content and only trace amounts of sulphur. In vehicle tests, it has loweremissions of carbon monoxide, soot, and polycyclic aromatic hydrocarbons than conventional diesel. With adjustments in the injection engine timing, it is possible to reduce the NOx emissions.

- Low Emissions
- It is biodegradable and non-toxic
- Low cost
- High Cetane Number
- High Lubricidity

VII. ELECTRICITY (BATTERIES & FUEL CELLS)

Electricity is a type of energy where mechanical power is derived directly from it, as opposed to other alternative fuels, which release stored chemical energy through combustion to provide mechanical power. Electricity in vehicles is commonly provided by rechargeable batteries, but fuel cells are also being explored.

A. *Environmental Characteristics*

Battery- powered electric vehicles are almost zero- emission vehicles. Fuel cell emissions, using hydrogen as the fuel, are water vapor and heat.

Electricity is unique among the alternative fuels in that mechanical power is derived directly from it, whereas the other alternative fuels release stored chemical energy through combustion to provide mechanical power. Motive power is produced from electricity by an electric motor. Electricity used to power vehicles is commonly provided by batteries, but recently fuel cells are also being explored.

B. *Battery:*

Batteries are energy storage devices. A large number of various types of batteries are being tested for use in electric vehicles. Some of the technologies include lead-acid, nickel cadmium, nickel iron, nickel zinc, nickel metal hydride sodium nickel chloride, zinc bromine, sodium sulphur, lithium, zinc air and aluminum air. On the other hand fuel cells convert chemical energy to electricity, which then power the motor.

Batteries are the storage "tanks" for electricity, and the quantity of potential power available from them is given by the battery rating (determined by plate size, quantity of electrolyte, etc.).

1) *Advantages of electric fuel:*

The advantages of electric fuel/fuel cells are:

- No tailpipe emissions.
- Vehicles using electric fuel demand less maintenance.
- Electric fuel vehicle have less moving parts to service and replace.
- Acceleration, speed and handling for well-designed vehicles are equivalent to, or better than, those of comparable internal combustion powered vehicles.
- Fuel cells vehicles are highly efficient.
- Fuel cells have high power density.

2) *Disadvantages of electric fuel:*

Some of the disadvantages of electric fuels are:

- Batteries may take time in charging.
- Weather extremes and use of accessories such as air conditioning can affect the range of electric vehicles.
- Noble metal required for some fuel cells thereby increasing the cost.
- Impurities in the hydrogen can hamper cell performance.
- Commercial production of hydrogen to cater to the fuel cells results in substantial copious CO2 emissions.
- Costly technology.
- Limited life of the battery is also a limitation of electric vehicles.

3) *Operation & Performance:*

The main features of operation and performance of electric vehicles are:

- Efficient operation when properly designed.
- Less moving parts demand less maintenance.
- Less noisy while in operation.
- Range spans from 50 to 130 miles depending on the vehicle weight, design and type of battery.

- Decrease in available specific energy in transient driving cycles and decrease in vehicle range with increased speed is reported.
- Sometimes cold weather may drop the specific energy, which the battery can store and hence vehicle range.

C. Fuel Cells

Today fuel cells are termed to be the most promising so far as generation of electricity is concerned. A fuel cell is an electrochemical energy conversion device. It is two to three times more efficient than an internal combustion engine in converting fuel to power. A fuel cell produces electricity, water and heat using fuel and oxygen in the air. Water is the only emission when hydrogen is the fuel.

Fuel cells do not store energy; instead chemical energy is converted into electricity. An external source of hydrogen (for example, from natural gas, gasoline, or one of the alcohol fuels) and oxygen (from air) are fed to the fuel cell. The electrolyte fuel cells employ the electrochemical reaction between hydrogen and oxygen to generate electricity.

1) Production:

Electricity is produced from power plants throughout the country, transmitted to substations through high voltage transmission systems, stepped down to lower voltages, and carried to homes and businesses through local distribution systems. This electricity is charged and stored in the onboard rechargeable batteries, which power the motor of the vehicles.

Like battery powered vehicles fuel cell vehicles use on-board electric motor. But while drivers must periodically recharge battery powered vehicles with electricity generated elsewhere, fuel-cell vehicles make their own power from on-board supply of hydrogen, or a hydrogen-rich fuel such as natural gas, methanol, ethanol or gasoline. This enables drivers to fill up at a service station, rather than recharge the car, making it a more practical solution for today' automobiles.

There are six basic types of fuel cells, solid oxide, phosphoric acid, alkaline, molten carbonate, direct methanol and Proton-Exchange Membrane (PEM).

The PEM fuel cell has several advantages for transportation use:

- High power density
- Relatively quick start up
- Compact size
- Low operating temperature
- Low noise levels.

2) PEM fuel cell components:

A basic fuel cell has three parts: An anode, a cathode and an electrolyte separating the anode from the cathode. In a PEM fuel cell, the electrolyte is a proton-exchange membrane. The fuel (Hydrogen) starts out at the anode and combines with oxygen at the cathode to form water. Since water is in a lower energy state than hydrogen and oxygen by themselves, there is a chemical potential that induces the hydrogen and oxygen to combine into water.

The hydrogen at the anode separates into individual protons and electrons, the constituent particles that comprise hydrogen atoms. A catalyst at the anode helps the separation occur. The membrane allows protons to pass through it, but not electrons.

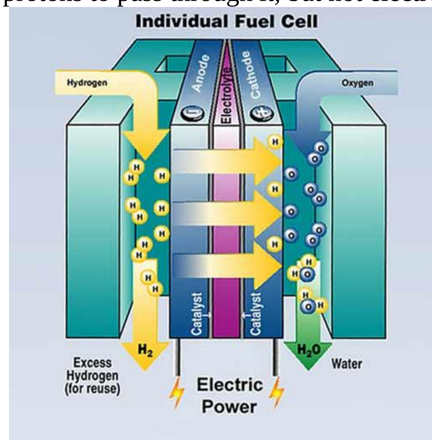

Fig 2:Components of Fuel Cell

The proton travel from the anode to the cathode through the membrane. Electrons travel from the anode to the cathode not through the membrane, but through an external device (electrical load). Moving electrons are by definition electricity. The electrons then travel to the cathode, where they recombine with the protons and oxygen to form water. A full size electric vehicle needs about 50 to 60 KW of power to accelerate and about 12.5 KW of power for cruising. A single PEM fuel cell has about 350 W of power, or 4 W per square inch of the cell area. To supply the necessary power, auto manufacturers may combine 150 and 200 individual fuel cells into a "stack".

Fuel cells require hydrogen to operate, but the storage of hydrogen and availability of hydrogen as a vehicle fuel pose challenges. Because of this, many fuel cell vehicles currently being developed to extract their hydrogen from another fuel, such as methanol or gasoline through the use of an on-board fuel processor or reformer.

3) Emissions:

Electric vehicles do not undergo any combustion process. Electric energy is the source of Mechanical power. There are no tailpipe emissions. Water is the only emission when hydrogen is used as the fuel in fuel cells. But the process of commercial hydrogen production to feed the fuel cell is associated with some CO_2 emissions.

CONCLUSIONS

Our dependence on energy is key to our economy and approach of life. Economically, new and renewable types of fuels are to be utilized, as our supplies of many current fuels are very limited. Environmentally, burning fossil fuels has been greatly affecting and damaging our planet.

Thus, it is necessary to compare all types of fuels, in order to determine the best ones, economically and environmentally, short term and long term in all aspects. And hence, alternative fuels are to be developed.

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