Parivesh
A News Letter from ENVIS Centre - Central Pollution Control Board

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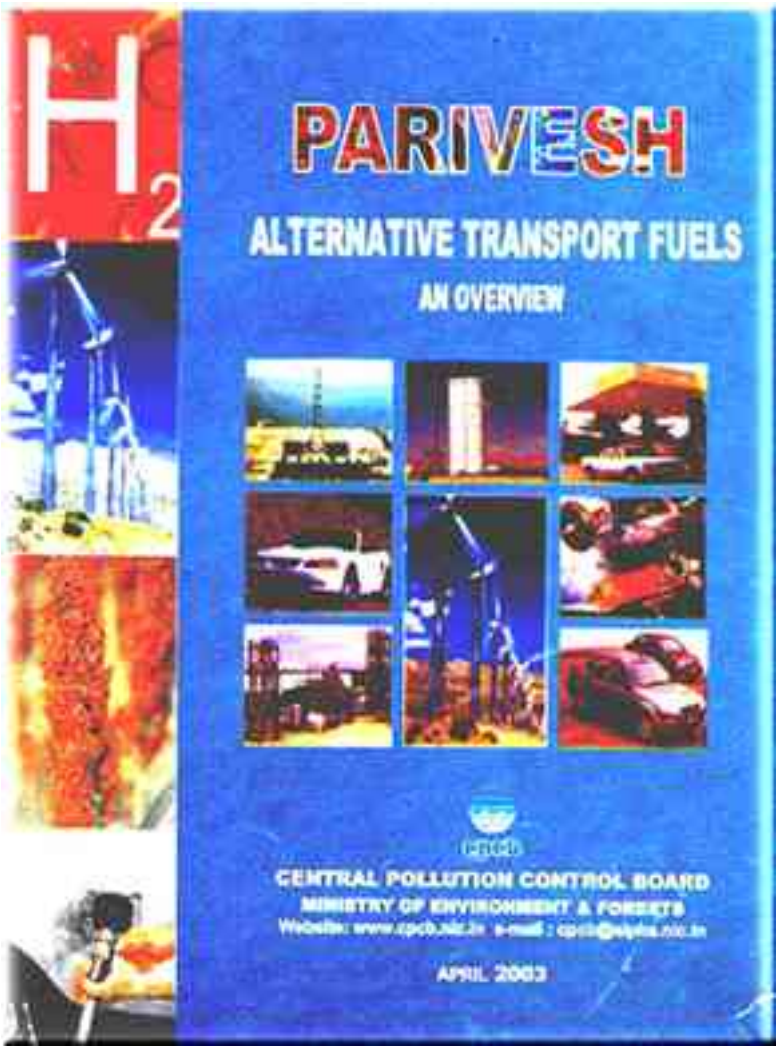

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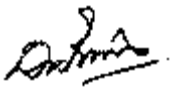
FOREWORD

With increasing oil import bills and diminishing stock of fossil petroleum fuels, search for renewable and domestic alternative propellants is now the prime challenge being faced by scientists and decision makers in India. Moreover, introduction of increasingly stringent vehicle emission legislation and severe air quality targets seem to question our reliance on the age-old conventional fuels. The future of mineral oils like gasoline and diesel and the prospect of clean alternative fuels, both depends on the limit of emissions allowed, legislative requirements, technical acceptability and the cost of the concept developed.

Our endeavur in exploring different alternative fuels like natural gas, alcohols, etc. is not new. During the 90s and mid-90s Central Pollution Control Board (CPCB) commissioned a study through the Indian Institute of Petroleum (IIP) to assess the feasibility of various alternative fuels for running automobiles. Several other organizations like Indian oil Corporation (R&D), Society for Indain Autiomobile Manufacturers (SIAM), Ashok Leyland, Tata Engineering, Scooters India ltd., Bajaj Auto ltd., Mahindra & Mahindra and other manufactrers have been carrying out field trials with alternate fuelled vehicles.

This issue of PARIVESH outlines pros and cons of various available alternate fuels including the initiatives taken in India for commercialization of the fuels. I am thankful to my colleagues Dr. B. Sengupta, Member Secretary, Dr. S.A. Dutta, Sr. Project Scientist and Shri R. Debroy, AEE for compiling this report.

We hope this will serve as a ready reference to the concerned authorities and general public.



(Dilip Biswas)
Chairman, CPCB

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INTRODUCTION

With the stock of fossil fuels diminishing throughout the world and demand for energy based comforts and mobility ever increasing, time is ripe that we strike a balance between energy security and energy usage. Moreover having uplifted to such a sphere of engineering excellence, reverting back to the ages of the bull carts will prove next to impossible thereby compelling us to search for a basket of alternative fuels to derive energy to cater to our needs. Several sources of energy, especially for driving the automotives are being developed and tested. Judicious utilization of this basket of energy is the call of the hour for a nation to see itself through the tough days ahead.

Today's engine development is heavily controlled by increasingly stringent emission legislation, leading to rapid developments. The EEV (Enhanced Environmentally Friendly Vehicles)-standards is coming into force for polluted cities, creating an extra incentive for the development of extra clean vehicle technology. The future of gaseous/alternative fuels depends on the maximum of polluting emission allowed, the technology available and the cost of concepts developed. Promising developments are taking place in the area of the conventional prime mover, the diesel engine.

At the end of the day the concept that fulfils all legislative requirements and can be sold at the lowest price will be the winner. And that may be an engine running on a conventional or on an alternative fuel or most likely on both.

The alternatives to petroleum-based fuels must meet the following criteria, if they are going to be used widely for transportation.

- Technical acceptability

- Economically competitive

- Environmentally acceptable

- Safety & availability.

Based on the above criteria, several alternate fuels have been considered from time to time all over the world as low cost

substitutes for gasoline and diesel. Lately they have gained importance as clean fuels. The prominent among these are, boidiesel, electric fuel, ethanol, hydrogen, methanol, natural gas (CNG/LNG), propane (LPG), DME, P-series and solar fuels.

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ETHANOL

1.0 ETHANOL

Ethanol (ethyl alcohol, grain alcohol, EtOH) is a clear, colourless liquid with a characteristic, agreeable odor. 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 feedstocks (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.

1.1 Production

The production phases in Ethanol production are shown in the following line diagram (Fig-1):

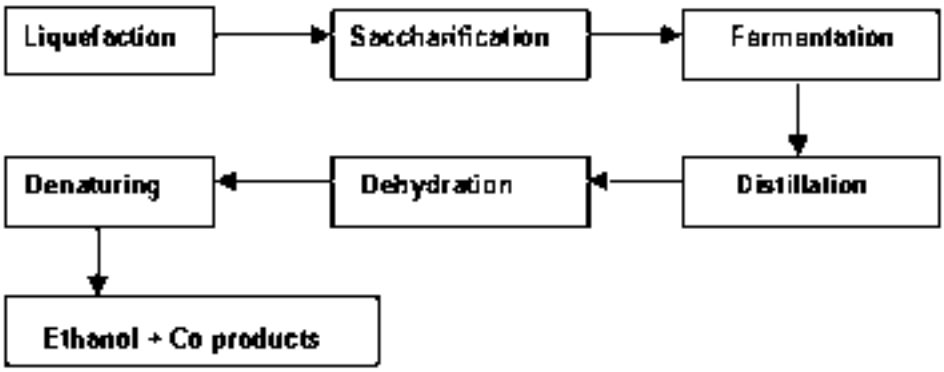

Fig-1: Ethanol Production Process

Fuel ethanol is denatured with small amount (2%-5%) of some product such as gasoline, to make it unfit for human consumption. Two main co products of ethanol production are CO2 and distillers grain. Many ethanol collect the CO2, clean it of any residual alcohol, compress it and sell it for use in carbonate beverages or to flash freeze meat.

1.2 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-1 shows the comparative emissions from ethanol and gasoline fuelled vehicle.

Table-1: Comparative Emissions (Ethanol Vs. Gasoline)

Emissions in g/mi	AFV-Ethanol	Gasoline
NHMC	0.10	0.10
CO	1.48	1.13
NOx	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 NOx

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 NOx (25% and 15% respectively), but particulates (PM10) remained unchanged.

1.3 Advantages of Ethanol:

Some of the advantages of Ethanol as an automotive fuel are:

- It reduces our dependence on imported fuels.
- It reduces air pollution.
- Ethanol is renewable.
- Refueling is akin to that of gasoline or diesel.
- Is applicable for both light and heavy-duty vehicles.
- More energy density compared to gasoline with optimized compression ratio.
- Maintenance assistance required is more or less identical to that of conventionally fueled vehicles.

1.4 Disadvantages of Ethanol:

Some of the disadvantages of Ethanol are:

- Demands frequent refueling keeping the volume of the tank unaltered.
- Use of special compatible lubricants required.
- Ethanol, especially E85 requires special replacement parts.

1.5 Operation and Performance:

- High energy density compared to gasoline.
- No loss in power, acceleration and payload.
- Special lubricants are required.
- Special parts required.

It is estimated that the US automakers have about 250,000 light-duty E85 vehicles on the road by the year 2000.

1.6 Storage & Distribution:

Storage and distribution of ethanol is quite similar to that of gasoline and diesel. E95 is available only through bulk suppliers.

1.7 Indian Initiatives on Ethanol:

In the year 1980, IIP and IOC, R&D conducted a study with ethanol as the fuel in some 13-passenger cars including army vehicles. The test included city driving, highway driving and hill driving conditions. Some of the findings of this study are:

- Loss in volumetric fuel economy of 1% and 3.9% with E10 and E20 fuels respectively under city driving conditions and 3.5% and 4.3% under highway driving conditions.
- Improvement in fuel economy in Ambassador and standard cars under hill driving conditions ranged from 4% to 13%.
- Cold starting at ambient temperatures from 0 deg C to 30 deg C remained unaffected.
- Hot startability and driveability demerits found higher with ethanol blends.
- No compatibility problems observed with metallic and non-metallic components.

Moreover a committee to look into all the aspects of introduction of Ethanol-Gasoline blend as an auto fuel was constituted by the MoP&NG. The committee was heading with the preliminary aim to introduce ethanol blends in the NCR but considering the economics and logistics, the committee could not mandate the introduction sometimes in the year 1999.

Ministry of Petroleum & Natural Gas launched three pilot projects in the country. The first project at Mirja was initiated on 15.4.2001; the 2nd at Bareilly on 22.6.2001 and the 3rd was launched at Manmad on 24.6.2001. Other technical and R&D activities are also been carried out in various parts of India.

Based on the experience of the pilot projects, Government of India on 29.11.2001 has taken a decision to introduce petrol blended with 5% ethanol for use in motor vehicles all over the country in a phased manner. In the first phase, the 5% ethanol blended petrol will be introduced in the States of Andhra Pradesh, Gujarat, Haryana, Karnataka, Maharastra, Punjab, Tamil Nadu and Uttar Pradesh. Rest of the States/Union Territories will be taken up in the second phase.

On the other hand, India is also working to blend 10% ethanol in petrol. The pilot projects and R&D initiatives are also lined up to study the feasibility of 10% ethanol-gasoline blend. Amendment in BIS specification to accommodate this 10% blend is being pursued

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METHANOL

2.0 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 contains no sulphur or complex organic species.

2.1 Production:

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. Infect today's economics favor its production from natural gas.

2.2 Emissions:

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

The following table (Table-2) gives emissions comparison between gasoline, M85 and M100.

Table-2: 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

2.3 Advantages of Methanol:

Some of the advantages of methanol when used as a fuel are:

- Methanol has very lower ozone forming potential.
- Emissions of sulphur and sulphur compounds are virtually negligible.
- Very low evaporative emissions due to its low vapour pressure.
- Easy refueling.
- Methanol is the most practical carrier of hydrogen to run fuel cells.
- Methanol has high-octane quality.

2.4 Disadvantages of Methanol:

The disadvantages of methanol include the following:

- High formaldehyde emissions.
- Acute toxicity.
- Availability is much dependent on the availability of natural gas.
- Low energy content compared to gasoline.
- Demands special lubricants and spare parts.
- May be costly.

2.5 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.

2.6 Safety Issues:

Methanol may not give rise too much safety concerns when used as automotive fuel but it is inherently toxic. Adequate training is required to operate and maintain methanol-fueled vehicles. Moreover neat methanol (M-100) also presents a special safety hazard as it burns without a visible flame and even alcohol-water wastes may be flammable.

2.7 Storage & Distribution:

Toxicity and solubility of methanol in water raises concern for safe storage and distribution. Adequate training is required to store, maintain & operate methanol-fueled vehicles though it has the refueling advantage like gasoline or diesel.

2.8 Indian Initiative on Methanol:

Indian Institute of Petroleum (IIP) in 1983-1986 conducted a fleet trail with M12 under the UNDP/UNIDO assisted programme on alternate fuel. M12 gasoline blend was used as the fuel in this study on 14 two wheelers of various makes. IIP also carried out some experimental studies on the two wheelers with methanol gasoline blends upto 20 %. Findings of the studies are summarized below:

- Operation beyond or over 15% methanol- gasoline blends was erratic and the engine started misfiring and hunting.
- With M15 it showed marginally better output and 3-4% improvement in fuel consumption.
- It established that upto 15% blends can be used without any engine modifications.
- Substantial reduction in carbon monoxide was recorded.
- No hot or cold driveability problems with M12 blends.
- Engine performance of M12 vehicles was found comparable to that of gasoline vehicles.
- Increase of wear with cast iron rings were observed.

In the year 1992, BIS standard was amended to facilitate the use of methanol in gasoline. Indian oil companies initiated a pilot scale project in November 1993 to market a methanol-petrol blend of 3% methanol called Petrol-M. This product was supplied from 10 selected retail outlets in the city of Baroda in Gujarat. Initially this project was taken up for a period of one year. The key findings of this project are:

- Blending, transportation and quality wise Petrol-M trail marketing was successful.
- A total quantity of 376 kl of the product was sold.
- It was comfortably used by cars, two-wheelers and three-wheelers.
- To tackle the apprehended problem of corrosive effect of methanol on engine parts, the oil industry used corrosion inhibitors.

CPCB also commissioned a study to evaluate the emission performance of methanol-gasoline blends through IIP sometimes in 1995-96. CPCB estimated that if all the petrol driven vehicles in Delhi use a methanol-gasoline blend of 3% methanol and 97% gasoline, it may be possible to have 11% reduction in hydrocarbons emissions, 7% CO reduction and 30% NOx reduction compared to pure gasoline driven vehicles.

ALCOHOL- DIESEL BLENDS (DIESOHOL)

3.0 ALCOHOL- DIESEL BLENDS (DIESOHOL)

Apart from ethanol/methanol-gasoline blends, ethanol/methanol-diesel blend is also another alternative option. Ethanol-diesel blend projects are under trial in Brazil and Sweden. Unlike ethanol-gasoline blend, ethanol-diesel blend has some concerns regarding lubricity, reduced flash point and startability problems.

3.1 International Experience:

Several technologies are currently under trials in different parts of the world. An Australian non-profit organization APACE has developed a ethanol-diesel emulsion agent which is under trial in Australia. Thailand, Chile, Malawi, Germany and Sweden. This diesohol technology claims successful blends up to 15% of ethanol in diesel. APACE claims that this emulsion, which allows use of hydrated ethanol with diesel, gives improvements in NOx, PM including PM2.5, hydrocarbons and also increases the thermal efficiency of the engine. Vehicles can use diesohol and diesel fuels interchangeably. The fire point of diesohol is higher than flash point and the magnitude of the difference depends upon the composition of the diesel fuel. Australian Government is currently in the process of developing fuel quality and operability standards for dieshol.

There are still several issues that need to be resolved before diesohol can be introduced commercially, some of the important issues are:

- Vapour lock-use of ethanol changes the vapour lock characteristics of the fuel.
- Material compatibility of pump seals, timing belts and some nitirle rubber seals used in the fuel injection systems of a vehicle is still a concern.
- Toxicity of the emulsifier.
- Dosage quantities of the emulsifier which may vary from base fuel to base fuel.
- Blend stability, especially at low temperature.
- Establishment of diesohol test standards.
- Stability under water addition.

3.2 Indian Initiative on Diesohol:

It is interesting that India was one of the earliest countries to recognize the merits of burning ethanol in diesel engines. The bi-fuel system developed by a German Professor H.A. Havemann & his colleagues at the Indian Institute of Science (IISc), Bangalore, in the early 50's is the earliest original published work in technical literature regarding alcohol diesel.

Government of India has sanctioned Rs. 4 crores for R&D studies on ethanol-diesel blends. MoP&NG is also working on to introduce 5% ethanol-diesel blend. For this purpose Indian Oil Corporation has selected some vehicle models to carry out trial tests on these vehicles. IOC (R&D) has also recommended SIAM members to carry out the tests trials with 5% ethanol-diesel blend, which are to be supplied by IOC. However, as on date BIS specification does not permit blending of ethanol and diesel.

Sufficient field trials in Indian conditions need to be carried out and its benefits on emissions, material compatibility and drivability, etc. may be assessed before trying this fuel in India.

There are some field trials data on methanol-diesel blends. IIP has developed a retrofit kit for dual-fuel operation of diesel vehicles with alcohols. IIP used the fumigation concept for this purpose and successfully demonstrated this system on MSRTC and DTC diesel buses under actual commercial passenger service. The fleet consisted of 25 & 35 buses of Tata and Ashok Leyland respectively with a total cumulative operation of 42,00,000 kms. The methanol fuel consisted of 10% gasoline also; to impart flame luminosity from the safety angle as the methanol flame is almost invisible in sunlight. The findings of the study are tabulated in Table-3.

Table-3: Results of IIP fleet study on Methanol-Diesel Blend

Number of Buses	60 Numbers
Total Operation	42,00,000 kms
Diesel Replacement	15-20%
Fuel Consumption	Comparable
Energy Efficiency	Better
Smoke Reduction	25-40%
Drivability	Good-to-Better
Oil Consumption & Degradation	Comparable
Engine Wear	Lower-to-Comparable
Engine Deposits	Lower-to-Comparable
Sludge Deposits	Marginally Lower
Material Compatibility	Adequate. Rubber components partially hardened

From the above work it was concluded that 15-20% substitution of diesel by alcohols is possible by a simple retrofit fumigation system. Even though more field trials are required on new generation diesel engines to assess the technical feasibility of the fuel.

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ELECTRIC FUEL

4.0 ELECTRIC FUEL

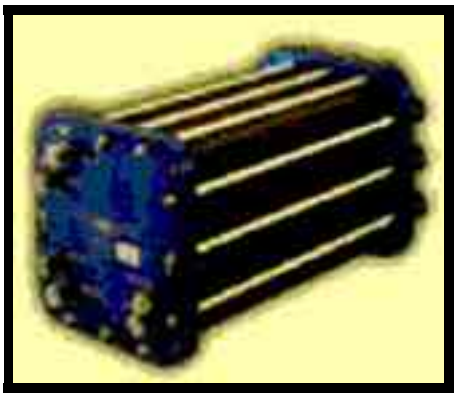
Electricity is unique among the alternative fuels in that mechanical power is derived directly from it, whereas the other alternative fuels release stored chemical energy through combustion to provide mechanical power. Motive power is produced from electricity by an electric motor. Electricity used to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

4.1 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.

4.2 Fuel Cell:

Day by day fuel cells are becoming the most promising so far as electricity generation 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.



4.3 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.

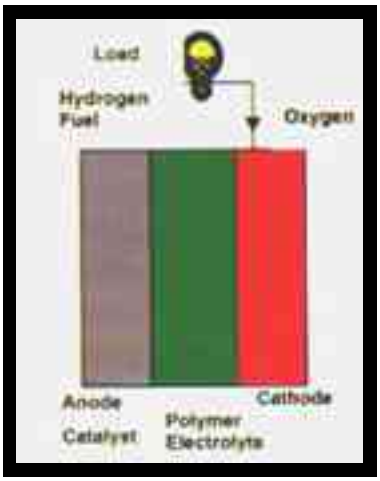
Like battery powered vehicles fuel cell vehicles use on-board electric motor. But while drivers must periodically recharge battery powered vehicles with electricity generated elsewhere, fuel-cell vehicles make their own power from on-

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's 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.

4.4 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.

The proton travel from the anode to the cathod 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.

4.5 Emissions:

Electric vehicles do not undergo any combustion process. Mechanical power is directly derived from electricity. 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 CO2 emissions.

4.6 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.

4.7 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.

More than 4000 electric vehicles are operating throughout the United States with the largest numbers in California.

4.8 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.

4.9 Safety Issues:

When designed properly the electric vehicles are quite safe. The battery or fuel cell stack on-board the vehicles contain enough charge to be fatal, so proper design and grounding should be done.

4.10 Storage & Distribution:

Electric vehicles require charging facilities, which automatically exists with the infrastructure of electricity utility distribution system. Fuels like methanol, ethanol etc. needed for extraction of hydrogen for fuel cells can be obtained from service stations. Installation of equipment at charging locations are expensive and sometimes charging may take much time depending on the remaining state of charge of the batteries and available voltage.

4.11 Indian Initiative on Electric Vehicles:

In India Bharat Heavy Electricals Ltd., Eddy Current Controls India Ltd., Cheetlec Vehicles India Ltd. and recently Bajaj

are established to produce electric vehicles. The technologies developed so far have reached a level to meet the basic operational requirements of urban road transport and industrial sector in a limited way. They are on their way to commercialise various models developed.

In the last Auto Expo during January 2002, several auto companies of India have displayed their model electric vehicles. Reva Electric Car Company, Bangalore displayed the first electric car of the country called "Reva". Bajaj and Mahindra & Mahindra have also developed electric vehicles in the country.

Government of India has shown interest in supporting the developments of electric vehicles. Ministry of Non conventional Energy Sources, Govt. of India have provided the following incentives to promote Evs in the country:

- Rs. 1000,000 per road vehicle
- Rs. 2000,000 in case of an additional battery
- Rs. 50,000 per industrial vehicle to a public, private sector users, Govt. Departments along with 100% depreciation in the first year and IREDA loans at 10% interest for 5 years.

Ministry of Non-conventional Energy Sources (MNES) has constituted a Committee in 2000 headed by Dr. Mashelkar. This Committee on " High Energy density Batteries for Electric Vehicles" also recommended for development of appropriate low weight and reasonable cost batteries for commercialization. Other operational programmes and field trial projects for Evs are also being taken up through a consortium approach of R&D organizations, manufacturers of batteries, ARAI, VRDE and other government agencies.

Several agencies including MNES have supported projects on different types of fuel cell technologies with the involvement of national laboratories, universities and industries with an aim to develop suitable materials, catalysts and components to strengthen manufacturing base for production of fuel cells in India. Small PAFC stacks have been developed and tested by BHEL. The SPIC Science Foundation of Chennai has developed an improved version of 5 kw fuel cell module. A research project is under implementation at the Central Glass and Ceramic Research Institute, Kolkata for the development of 1 kw SOFC power pack. Indian Institute of Science, Bangalore will construct a 100-watt liquid-feed solid polymer electrolyte direct method fuel cell (DMFC). IIT, Chennai is also developing in collaboration with SPIC a 250-watt DMFC stack. Comparision of different fuel cell technologies is given in Table-4.

Table-4: Comparison of Five Fuel Cell Technologies

Fuel Cell	Electrolyte	Operating Temperature (0C)	Electrochemical Reactions
Polymer Electrolyte Membrane (PEM)	Solid organic Polymer Poly-perfluorosulfonic acid	60-100	Anode: $H_2 \rightarrow 2H^+ + 2e$ Cathode: $\frac{1}{2} O_2 + 2H^+ + 2e \rightarrow H_2O$ Cell : $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$
Alkaline (AFC)	Aqueous solution of Potassium hydroxide Soaked in a matrix	90-100	Anode : $H_2 + 2(OH) \rightarrow 2H_2O + 2e$ Cathode : $1/2O_2 + H_2O + 2e \rightarrow 2(OH)$ Cell : $H_2 + 1/2O_2 \rightarrow H_2O$
Phosphoric Acid (PAFC)	Liquid phosphoric Acid soaked in a matrix	175-200	Anode : $H2 \rightarrow 2H^+ + 2e$ Cathode : $1/2O_2 + 2H^+ + 2e \rightarrow H_2O$ Cell : $H_2 + 1/2O_2 \rightarrow H_2O$
Molten Carbonate (MCFC)	Liquid solution of Lithium, sodium and/ Or potassium, soaked In a matrix	600-1000	Anode : $H_2 + CO_3^{2-} \rightarrow H_2O + CO_2 + 2e$ Cathode : $1/2O_2 + CO_2 + 2e \rightarrow CO3^{2-}$ Cell : $H_2 + 1/2O_2 + CO_2 \rightarrow H_2O + CO_2$ (CO_2 is consumed at cathode)
Solid Oxide (SOFC)	Solid zincronium oxide To which a small Amount of ytria is added	600-1000	Anode : $H_2 + O^{2-} \rightarrow H_2O + 2e$ Cathode: $1/2O_2 + 2e \rightarrow O^{2-}$ Cell : $H_2 + 1/2O_2 \rightarrow H_2O$

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HYBRID ELECTRIC VEHICLES

5.0 HYBRID ELECTRIC VEHICLES

Hybrid Electric Vehicles (HEVs) combine two or more energy conversion technologies (e.g., heat engines, fuel cells, generators, or motors) with one or more energy storage technologies (e.g., fuel, batteries, ultracapacitors, or flywheels). The combination of conventional and electric propulsion systems offers the possibility of greatly reducing emissions and fuel consumptions, while giving consumers both the extended range and convenient refueling they expect from a conventional vehicle. HEVs can either have a parallel or series design. In a parallel design, the energy conversion unit and electric propulsion system are connected directly to the vehicle's wheels. The primary engine is used for highway driving; the electric motor provides added power during hill climbs, acceleration, and other periods of high demand. In a series design, the primary engine is connected to a generator that produces electricity. The electricity charges the batteries and drives an electric motor that powers the wheels.

The Toyota Prius and Honda Insight were two models of hybrid electric vehicles introduced in the United States in 1999 and 2000. Other auto manufacturers are working on developing and commercializing HEVs in the market.

5.1 Advantages of HEVs:

The advantages of HEVs are:

- HEVs are two or three times more fuel efficient than conventional vehicles.
- Good emission benefit.
- Extended vehicle range.
- Easy and rapid refueling.
- Compensates the shortfall in battery technology.
- Application of regenerative braking helps minimize energy loss.
- HEVs can run on alternative fuels thus can reduce the dependency on fossil fuels.

5.2 Disadvantages of HEVs:

Hybrid electric vehicles enjoy many advantages overruling the demerits associated with it, if any. As these vehicles are very recently introduced in the market, data on their on-road performance and servicing requirements are yet to be analysed.

5.3 Indian Initiative on HEVs:

In India, Ashok Leyland has developed a model hybrid bus in collaboration with ER&DCI. This hybrid bus has been displayed in the 2002 Auto Expo. Indian manufacturers are investing in R&D to bring out some HEV models.

HYDROGEN

6.0 HYDROGEN

Hydrogen is the most abundant element in the universe, but is rarely found in its uncombined form on the earth. Hydrogen gas (H2) is being explored for use in combustion engines and fuel cell electric vehicles. When combusted (oxidized) it creates only water vapor as a by-product. When burned in an internal combustion engine, however, combustion also produces small amounts of nitrogen dioxides and small amount of unburned hydrocarbons and carbon monoxide because of engine lubricants but the exhaust is free from carbon dioxide. It is a gas at normal temperature and pressure, which presents greater transportation and storage hurdles. Storage systems being developed include compressed hydrogen, liquid hydrogen and chemical bonding between hydrogen and a storage material (for example, metal hydrides).

6.1 Production:

Two methods are generally used to produce hydrogen- electrolysis and synthesis gas production from steam reforming or partial oxidation. Electrolysis uses electrical energy to split water molecules into hydrogen and oxygen. The electric energy can come from any electricity production sources including renewable fuels. The predominant method for producing synthesis gas is steam reforming of natural gas, although other hydrocarbons can be used as feedstocks. For example, biomass and coal can be gasified and used in a steam reforming process to produce oxygen.

Another development using hydrogen is a blend of hydrogen and methane (natural gas) called Hythane.

6.2 Emissions:

Hydrogen is one of the simplest and the lightest fuel. On combustion it produces only water vapor as the by-product. It has the greatest potential for reducing emissions. There may be small amount of unburned hydrocarbons and carbon monoxide, which may be attributed to the engine lubricants.

6.3 Advantages of Hydrogen:

Some of the advantages of hydrogen as a fuel include:

- Very less emissions.
- High octane rating.
- High energy content.
- Large base source for production is available.

6.4 Disadvantages of Hydrogen:

Disadvantages of hydrogen fuel are:

- Infrastructure.
- Problem of fuel storage.
- Vehicle range and power loss.

- Wider flammability limits.
- Costly production.
- Limited field trial experience.

6.5 Operation & Performance:

Operational and performance data are not adequate, as no vehicle exists currently that run on hydrogen as a fuel excepting some test vehicles in the USA. But some studies found operation and performance of hydrogen vehicles very promosing.

6.6 Safety Issues:

Especially for hydrogen, safety is mainly a function of storage method, and both refueling and vehicle storage system require extensive development. Storage technologies include high-pressure storage, cryogenic liquid storage and low-pressure metal hydride storage systems.

6.7 Vehicle Experience:

There are no commercial vehicles currently available that use hydrogen as fuel, however automobile manufacturers have experimented with developing vehicles that use hydrogen. Research vehicles have been produced by Daimler-Benz, BMW and Mazda. The Mercedes-Benz and BMW vehicles use liquid hydrogen. The Mazda vehicle stores its hydrogen as a gas in a metal-hydride lattice of shaved metal. Other vehicles have been built using compressed hydrogen, including two vehicles in Arizona operated by the American Hydrogen Association.

6.8 Storage & Distribution:

Hydrogen is a gas at normal temperature and pressure. It can be stored as a compressed gas like CNG or in liquefied cryogenic form or in the form of metal hydrides. Lot of developments is needed for efficient and effective storing of hydrogen. Economic and safe storing of the fuel on board a vehicle is the main challenge now. Extensive research is going on in this field and researchers are hopeful of getting a breakthrough soon.

6.9 Indian Initiative on Hydrogen:

Researchers in India have developed a hydrogen-powered motorbike that its developers believe is ready for commercialization. The technology, based on a novel metallic hydrogen storage system, may also be modified for use in cars. As a part of a R&D project, a photo bioreactor for producing hydrogen from distillery wastes treatment was installed at Nellikuppam in Tamil Nadu. Other projects were also taken up for the production of hydrogen using solar energy and water through photo electrochemical/photocatalytic methods. Government of India is also funding a project at BHU, Varanasi for performance improvements of hydrogen/metal hydride-based vehicles. Another research project for pilot scale production of hydrogen by photo catalytic decomposition of water using semiconductor photo catalyst, which can be activated by radiation, is under implementation at BHU. Moreover, BHU has also taken up a project for the development of hydrogen storage materials and systems for vehicular applications.

MNES proposes to launch a field operations programme on hydrogen energy for vehicular applications.

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NATURAL GAS

7.0 NATURAL GAS

Natural gas is a mixture of hydrocarbons-mainly methane (CH4) 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 exhaust emissions, low noise, less maintenance, not prone to adulteration, driver's comfort, etc. are some of the attractive features of CNG as an automotive fuel.

7.1 Production:

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.

7.2 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, 7 and 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. Life cycle emissions analysis of alternate fuels. CSIRO report to Australian Greenhouse Office, March, mimeo

Table-5: Emission Results for Bajaj Three-Wheelers

Type	CO	THC	NMHC	Nox
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

Pollutant	Test Results (gms/Kwh)	
	CNG	Diesel
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

Manufacturer	Year of Mfg.	Capacity (Ltr.)	Emissions in gm/kWh			
			CO	THC	NMHC	NOx
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	5.675	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 LEYLAN	1992	6.075	9.3	5.09	0.70	12.0

7.3 Advantages of CNG:

Following are some of the benefits of CNG when used as an automotive fuel:

- No visible tail pipe emissions.
- Eliminates sulphur and lead from the exhaust emissions.
- Reduction in CO, NOx and Particulate emissions.
- Significant reduction in benzene and other toxic emissions.
- Higher octane value of CNG reduces knocking problems of a vehicle.
- Reduces noise from running vehicles.

- CNG cannot be adulterated.
- Reduce noise in operation.

7.4 Disadvantages of CNG:

CNG is now established as a very successful alternate fuel for automobiles throughout the world. The disadvantage of this fuel, if any is easily overruled by the advantages associated with this fuel. Nevertheless, infrastructure, on-board storage and issues on safety need proper attention for this fuel.

7.5 Safety Issues:

Natural gas is neither corrosive nor toxic, its ignition temperature is high, it is lighter than air, and it has a narrow flammability range, making it an inherently safe fuel compared to other fuel sources. Natural gas cannot contaminate soil or water. It will always rise to the atmosphere out of doors, unlike other fuels, which are heavier than air and can pool, either as a liquid or a vapor, upon the ground. Natural gas contains a distinctive odorant (mercaptan), which allows natural gas to be detected at 0.5% concentration in air, well below levels that can cause drowsiness due to inhalation and well below the weakest concentration that can support combustion. Due to high ignition temperature of natural gas (540 degree C), simple exposure to a hot surface (such as exhaust manifold) is unlikely to lead a fire.

7.6 Indian Initiative on CNG:

After several trails and field studies by various institutions and taking stock from the experience of other countries, India too initiated to introduce CNG as automobile fuel. Recently large numbers of buses, autos and taxis in Delhi have been switched over to CNG (Table-9). Initially there have been problems of infrastructure and dispensing stations but slowly things are getting back to normal in Delhi. At present there are 97 dispensing stations in Delhi with a total compression capacity of 7.9 lakhs kg/day and dispensing capacity of 6.0 lakhs kg/day. CNG vehicles are also present in Mumbai and Baroda. Acknowledging the impact of CNG on the air quality of Delhi other cities of India are also taking up plans for introducing CNG in a phased manner.

Table-9: Present Status of CNG Vehicles in Delhi (as on September 2002)

Vehicles	Numbers
(DTC) Bus	2,123
Private Bus	4,686
RTVs	3,423
Three Wheelers (Autos)	43,903
Taxis	5,226
Total	69,717

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LIQUIFIED PETROLEUM GAS (LPG)

8.0 LIQUIFIED 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-10.

Table-10: 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

8.1 Production:

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.

8.2 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-11 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-12. Non-regulated components of emissions like aldehydes and poly-aromatic hydrocarbons are much lower from CNG vehicles compared to that of diesel vehicles.

Table-11: 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%
NOx/10 (g/km)	1.254	0.54	-57%
Particulates (g/km)	0.028	0.017	-39%
CO2/1000 (g/km)	1.344	1.309	-4%

Source: Millebrook-ref:9.

Table-12: Comparison of non-regulated Emission (Diesel Vs. LPG)

Emission Component	Euro-II Diesel Bus	LPG Bus
Toxic Effects (%)		
PAH	100	< 15 % 35%
BTX	100	20 to 40%
Lower Aldehydes	100	
Summer Smog Potential (Ethene Equivalent) (%)	100	40%
Acidification (%)	100	20 to 50%
Winter Smog Potential (%)	100	< 15 %

Source: The Alternative Fuels Directory-TNO, 1998.

8.3 Advantages of LPG:

Some of the benefits of LPG as automotive fuel are:
- Reduction in emissions.
- Very less carbon build-up increases life of engine parts like spark plugs.
- Fueling is akin to that of conventional diesel or gasoline and time needed is also similar.
- Service life of a vehicle increases with LPG.
- Little or no damage to soil and water if it is spilled, due to its rapid evaporation.
- Higher octane number.

8.4 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.

8.5 Safety Issues:

Safety is an issue with LPG, however, standards for application, storage and distribution already exists. The hazard associated with on-board storage should be similar to that of gasoline, especially if reinforced cylinders similar to that of CNG tanks are used. LPG fuel systems have many built-in safety features and they generally maintain their integrity in severe collisions and do not permit massive leaks. LPG is about twice as heavier than air and unlike CNG does not disperse easily in air. Its flammability limits (2.1-9.5 vol.%) and auto ignition temperature (450 degrees C) are also lower than natural gas and as such should not be handled carelessly. Accident statistics, though limited, indicate that LPG or propane is as safe as gasoline.

8.6 Indian Initiative on LPG:

In India, initiatives for evaluating the performance of LPG as automotive fuel dates back to 80s and mid-80 when IIP, Dheradun carried out some field studies on bus and tractor engines using commercially available duel-fuel engine kits. Studies on diesel engines were also conducted at IIT Madras and Anna University, Madras. Some manufacturers in India already acquired the technology for producing LPG version of their products, especially two wheelers but huge demand of LPG for domestic cooking seems to discourage its lunch in the automobile sector in a big way.

In India, the Committee of experts appointed to study introduction of LPG as an auto fuel has submitted its recommendations and Government of India has already passed legislation enabling use of LPG as automotive fuel Government has accorded approval for developing 201 Auto LPG dispensing facilities in the existing retail networks. Bharat Petroleum Corporation (BPC) has developed one auto LPG dispensing facility in Delhi as a pilot project. Moreover, comprehensive regulatory and safety framework for the fuel is under development.

Moreover, a pilot project was also initiated in Delhi for conversion of two-stroke petrol three-wheelers to Propane. Accordingly, three propane-dispensing stations were set up in Delhi (Vinodnagar, Mayurvihar, Okhla) with the assistance of G&T Resources Worldwide (USA). However, this project was withdrawn at a later stage.

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DIMETHYL ETHER (DME)

9.0 DIMETHYL ETHER (DME)

Dimethyl Ether (DME) is an ether compound having a molecular structure in which one oxygen atom and two methyl groups are bonded. It is chemically synthesized from natural gas, coal-associated, etc. DME is a gas looking colourless and smelling etheric at room temperature and under normal pressure. Like LPG, DME is liquefied by applying a pressure of approximately 0.5 Mpa.

9.1 Emissions:

Table 13 and 14 show a comparison of engine performance and emissions between diesel and DME buses. The table indicates that a DME engine, although having an equal energy efficiency level to that of a diesel engine, emits extremely low NOx and particulate matters. From Table-14 it is clear that DME bus easily meets the Euro-IV diesel standards. A DME vehicle outperforms diesel vehicles for regulated emissions like NOx, total hydrocarbons and particulate matters. Peak acceleration smoke of a DME vehicle is almost nil and it also performs better with regard to combustion noise when compared to that of a diesel vehicle. DME is now being tried in USA and Japan to achieve severe emission reduction targets of as low as 50% of the proposed Euro-IV levels. Fuel economy of a DME vehicle is also found to be comparable to that of conventional diesel vehicle. Volvo is working on to further reduce emissions from their DME buses, which at present easily meets the equivalent Euro-IV standards.

Table-13: Comparison of Engine Performance (Diesel Vs. DME)

	Diesel	DME
Rated Power/Torque	Equal	
Fuel Economy (Energy Basis)	Equal	
Transient Cycle Emissions		
NOx (g/bhp-h)	3.8	1.8
THC (g/bhp-h)	0.3	0.3
Particulates (g/bhp-h)	0.08	0.02
Peak Accel. Smoke (%)	5%	0%
Maximum Combustion Noise dB (A)	88	78

Source: JARI/JICA, Japan, TBC/JR; 02-104.

Table-14: Emissions of VOLVO DME Bus

EMISSIONS		VOLVO DME	EURO-IV LIMIT
CO	(g/kwh)	0.25	1.5
THC	(g/kwh)	0.12	0.46
NOx	(g/kwh)	3.0	3.5
PM	(g/kwh)	0.002	0.002

Source: JARI/JICA, Japan, TBC/JR; 02-104.

9.2 Advantage of DME:

The greatest advantage of DME when used as an automobile fuel is that its high cetane number makes it applicable to a diesel engine and being an oxygen containing fuel, it prevents a diesel engine from emitting soot and particulate matter to a greater extent than diesel fuel does.

9.3 Disadvantage of DME:

Some of the disadvantages of DME are:

- DME has a viscosity lower than that of diesel.
- Lubricity is also low causing wearing of engine parts.
- It is found to react with some rubber components

9.4 Technology Development Trend of DME Vehicles:

DME vehicles are under developmental stage in many countries of the world. Several developmental projects are being promoted for commercializing this fuel. The Danish Government in cooperation with petroleum and automobile manufacturers is pushing ahead the Scandinavian Bus Project. This is the demonstration project aiming to introduce low-emission DME buses to public transportation. Specifications of the VOLVO DME bus used in this project are given in

Table-15.

Table-15: Specifications of VOLVO DME Bus

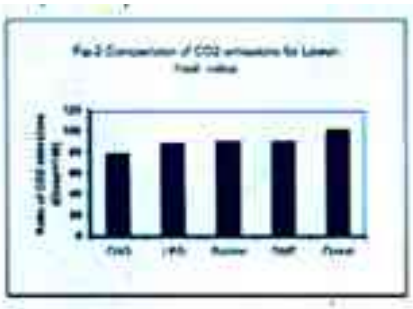
Engine	Displacement	9.6 L
	Maximum Power	245PS/2,000 rpm
	Maximum Torque	1,050 NM/1,450 rpm
	Injection System	Common-Rail
Fuel System	DME Storage Tank Volume	690 L
	Purge Tank Volume	180 L

Source: JARI/JICA, Japan, TBC/JR; 02-104.

Another project, the PNGV project is a research programme of the US Federal Government and USCAR (United States Council for Automotive Research). The researcher of this project concludes that in the short term, synthetic diesel fuel like DME is not commercially very viable but it holds promise for the future. Renaut, TNO, Peugeot PSA and IFP has launched a project in 2000 called the "European DME Passenger Car Demonstration Programme" with the objective to achieve emission targets of 50% of Euro-IV limit values for regulated emissions and LPG/CNG levels for non-regulated components. Some projects on DME are also going on in Japan.

9.5 Comparison of CNG/LPG/DME:

Compressed Natural Gas (CNG), Liquified Petroleum Gas (LPG) and Dimethyl Ether (DME) are the three prominent gaseous alternatives to conventional fuels. CNG and LPG have already penetrated as automotive fuels in many parts of the world and DME is also fast emerging as a promising alternative. Comparisons of some of the properties of these fuels with diesel are given in Table-16. Figures-2 & 3 show the comparison of CO2 emissions and energy density of the fuels respectively.



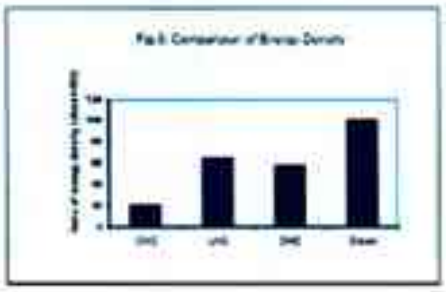


Table-16: Comparison of Properties of some fuels

Properties		Natural Gas	Propane	Butane	DME	Diesel
Chemical Structure		CH_4+rest	C3H8	C4H10	CH3OCH3	-
Molecular Weight	(g/mol)	18.7	44.1	58.1	46.1	170
Liquid Density	(kg/m3)	465	500.5	578.8	667	831
Cetane Number		-	-	-	>55	40-55
Octane Number	(RON)	120	112.1	91.8	-	-
Stoich. A/F ratio	(kg/kg)	16.9	15.7	15.5	9.0	14.6
Boiling Point		-162/-88	-42	-0.5	-25	180/370
Vapour Pressure [@293k]	kpa	-	830	210	530	-
Lower Heat Value	(MJ/kg)	49	46.4	45.7	28.8	42.7
Auto-Ignition Temperature		650	470	365	235	250
Gaseous Sp. Heat	(kJ/kg K)	2.2	1.67	1.68	2.99	1.7
Heat of Vaporisation	(kJ/kg)	510	372	358	467	300

Source: JARI/JICA, Japan, TBC/JR: 02-104

9.6 Indian Initiative on DME:

Recognizing that DME can be a new economical fuel for the 21st century, India's Ministry of Petroleum & Natural Gas invited British Petroleum (BP) in 1997 to develop DME supplies in an exclusive partnership with India's leading energy marketers and research organizations. In July 1998, a collaboration agreement was signed between BP, IOCL, GAIL and IIP for development, production and marketing of DME as a multi-purpose fuel for India. DME will be produced through Gas-to-Liquid (GTL) technology and for this gas will be sourced from the Middle East. Intention of this project was to establish DME as a multi-purpose fuel for India but in the initial stages the project identified some southern Indian states to supply DME as a feedstock for power plants.

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BIODIESEL

10.0 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. For more information on biodiesel please refer to our PARIVESH newsletter on Biodiesel.

10.1 Emission Characteristics:

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-17.

Table-17: Biodiesel Emissions Compared to Conventional Diesel

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%	

Sulphur Dioxide (LCA)	-100%

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

10.2 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.

10.3 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.).

Indian initiative on biodiesel, safety issues and storage/handling for biodiesel is described in our earlier publication PARIVESH on biodiesel. Properties of biodiesels from various feedstocks are given in Table-18.

Table-18: Some properties of different biodiesel fuels

Biodiesels	**Melting Range,(Degrees Centigrade)**				
	Oil/Fat	Me. Ester	Et. Ester	Iodine No.	Cetane No.
Rapeseed oil, h.eruc.	5	0	-2	97-105	55
Rapeseed oil, l.eruc.	-5	-10	-12	110-115	58
Sunflower oil	-18	-12	-14	125-135	52
Olive oil	-12	-6	-8	77-94	60

Soyabean oil	-12	-10	-12	125-140	53
Cotton seed oil	0	-5	-8	100-115	55
Corn oil	-5	-10	-12	115-124	53
Coconut oil	20-24	-9	-6	8-10	70
Palmkernel oil	20-26	-8	-8	12-18	70
Palmoil	30-38	14	10	44-58	65
Palm oleine	20-25	5	3	85-95	65
Palm stearine	35-40	21	18	20-45	85
Tallow	35-40	16	12	50-60	75
Lard	32-36	14	10	60-70	65

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P-SERIES FUEL

11.0 P-SERIES FUEL

P-Series is a new fuel that is now classified as an alternative fuel by the US Department of Energy. This fuel was developed by Dr. Stephen Paul of Princeton University. This class of P-Series fuel includes certain blends o methyltetrahydrofuran, ethanol and hydrocarbons. Pure Energy Corporation of USA holds the exclusive worldwide license to manufacture and distribute the P-Series fuels. Pure Energy Corporation's P-Series fuels are blends of ethanol, methyltetrahydrofuran (MTHF) and pentanes plus with butane added for blends that would be used in severe cold-weather conditions to meet the cold start requirements. Both ethanol and MTHF to be derived from renewable sources.

11.1 Production:

Ethanol and MTHF, the main components of P-Series fuel are produced first through an integrated process. Pure Energy Corporation expects to utilize commercially proven concentrated acid hydrolysis processing as its base technology for this integrated production process. MTHF is currently produced in limited quantities from furfural (derived from both biomass and petroleum feedstocks) for use as a specialty chemical in consumer end products and in process industries. Pure Energy Corporation has developed a thermo- chemical technology to produce MTHF from cellulosic feedstocks through a levulinic acid pathway, integrating it with an ethanol production system to achieve technical and economic efficiencies. In this process, the lignocellulosic feedstock is converted into both five- and six-carbon sugars, which are then bifurcated into fermentation and thermo-chemical pathways to produce ethanol and MTHF respectively.

11.2 Emissions:

Emissions from P-Series fuels are substantially lower than that of conventional fuels. A comparative emission test result with P-Series (32% Pentanes Plus+50% Ethanol+18% MTHF) is given in Table-19.

Table-19: Comparative Emissions from P-Series Fuel

Pollutants (g/mile)	UTG-96	RFG-II	COMS	E-85	P-Series
NMHC	0.14	0.11	0.14	0.12	0.07
NMOG	0.15	0.13	0.16	0.21	0.08
CO	1.40	1.20	1.40	1.20	1.00
CO_2	422	417	422	379	407
Ozone Potential	0.48	0.46	0.52	0.48	0.30
Miles/Gallon	21	20	21	15	19

Source: Test performed on Ford Tauras at Automotive Testing Lab., Ohio, 1998.

11.3 Advantage of P-Series Fuel:

P-Series fuels contain at least 60% non-petroleum energy content derived from MTHF and ethanol. Most of the components of this fuel can be derived from renewable domestic sources thereby making it a choice for energy security. Moreover, it also gives emission benefits as compared to conventional fuels.

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WATER-DIESEL EMULSIFIED FUEL (PURINOX)

12.0 WATER-DIESEL EMULSIFIED FUEL (PURINOX)

The benefits of adding water to diesel fuel have been known for some time. Water promotes a finer, cloud-like atomization of the fuel mixture during injection and modifies combustion, resulting in substantial reductions in nitrogen oxides and particulates. However, the challenge has been keeping the fuel/water mixture stable in storage and keeping the water away from engine parts. Several companies are now claiming to have tackled this problem of storage stability by various chemical methods.

Lubrizol Corporation has accomplished this goal by using specialized chemistry to completely surround the water droplets with a chemical shell, which prevents the water from separating out of the fuel, and results in a stable fuel blend. Lubrizol Corporation has patented and termed this as PuriNox. This water-diesel emulsified fuel has shown promising results in reducing emissions of NOx by over 30% and particulates by over 50% when used as an automotive fuel.

TOTALFINAELF, an oil company headquartered in France has also developed one water-diesel emulsification called Aquazole. Aquazole also reduces emissions significantly when used as automotive fuel. Both Purinox and Aquazole have been verified by the CARB for emission performance.

12.1 Production:

Lubrizole's Purinox chemistry allows up to 20% water to be added to diesel fuel to improve combustion and reduce emissions. Lubrizol has developed and patented a blending unit for blending the fuel. This unit has demonstrated its ability to repeatedly produce a stable finished fuel. The blending unit includes safety features such as spill containment and explosion proof controls. Advanced automatic metering technology precisely controls the quality of the fuel.

12.1.1 Emissions:

The California Air Research Board (CARB) has verified both Purinox and Aquazol. In January 2001, the CARB declared the verification of Purinox emulsion by Lubrizol and certified this fuel to provide a NOx reduction of 14% and PM reduction of 62.9%. Soon after, Aquazol of Totalfinaelf was also verified by the CARB and recorded to give 16% and 60% reductions in NOx and PM respectively. This CARB verification confirms the emission reduction ability of the fuels but the verification does not address possible impacts of emulsified fuels on engine durability or performance.

12.2 Advantage of water-diesel emulsion:

Some of the advantages of this emulsified fuel are:

- This is a simple process.
- Very good emission reduction potential, especially NOx and PM.
- Storage (when stable) & distribution is akin to that of conventional fuels.
- The fuel may be used for heavy-duty CI engines also.
- Reduces emissions in old engines also.
- Ample scope of cost reduction in future.

12.3 Disadvantages of water-diesel emulsions:

The following are some of the drawbacks of the fuel:

- Since water carries no energy value, there is a loss of power.
- Long-term storage stability of the fuel is still a concern.
- Engine durability and performance data with the fuel is not adequate.
- Possibility of adulteration cannot be ruled out.

12.4 Operation & Performance:

Currently over 6000 vehicles worldwide run on water-diesel emulsion. Italy has the maximum share of 4000 vehicles. London and Nottingham also has a sizable population of the centralized bus currently running on this fuel. This fuel is found to give reduced power at peak power. More data on engine durability and performance is still required.

12.5 Indian Initiative on water-diesel emulsified fuels:

The issue of water-diesel emulsified fuel was discussed in the Expert Committee of the Auto Oil Policy. Society of Indian Automobile Manufacturers (SIAM) has expressed its reservations on the effect of diesel-water emulsion on the fuel injection pump durability and they also apprehended that the additives used may cause aldehyde emissions.

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SOLAR FUEL

13.0 SOLAR FUEL

Recently there has been some research to evaluate how solar energy may be used to power vehicles, however, the possibility of operating a vehicle on solar energy or solar fuel is very slim. The research on solar power is slowly shifting to the idea of using the solar energy to run certain auxiliary systems in the vehicle. Solar energy is derived from the sun. In order to collect this energy and use it to fuel a vehicle, photovoltaic cells are used.

13.1 Indian Initiative on Solar Energy:

Solar and wind power systems are already in commercial use across the country today. India infact has one of the world's largest solar photovoltaic industries. India has more than 350,000 solar photovoltaic systems installed in the country. Solar energy initiatives started in India as early as 70s and lot of developments have taken place since then but most of the efforts are concentrated to generation of electricity.

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COMPARISION OF SAFETY ISSUES OF ALTERNATE FUELS

14.0 COMPARISION OF SAFETY ISSUES OF ALTERNATE FUELS

The criterion of safety is very important for selection of alternative transportation fuels. With the number of alternate fuelled vehicles increasing diverse issues on safety are emerging out. Safety analysis of the fuel on-board a vehicle is not the only requirement today, safety issues pertaining to bulk-transportation of the fuel, storage & handling, spills; leakages, etc. also need to be assessed today.

Tables-20 and 21 lists the safety aspects of different alternative fuels pertaining to transportation and storage of the fuels. Figures-4 to 8 describes some comparative properties of various alternative fuels. Table-22 shows the representative emissions from various alternative fuels.

Table-20: Relative Potential for Spills during Transport

Alternate Fuels	Leak Potential Compared to petrol/diesel spill	Reason
Gasoline/Diesel	Reference Fuels	
Ethanol/Et. Blends	Somewhat Higher	Potential Corrosion effect
Methanol/Blends	Somewhat Higher	Potential Corrosion effect
Propane	Higher	Pressures up to 375 psi
LNG	Higher	300 F temp. differentials and Pr. Up to 150 psi

Table-21: Relative Potential for Leaks during Transport

Alternate Fuels	Spill Potential Compared to petrol/diesel spill	Reason
LNG	Lower	Double walled cryogenic transport tanks
Propane	Lower	High pressure transport tanks
Gasoline/Diesel	Reference Fuels	
Ethanol/Et. Blends	Same	Same tank as petrol/diesel
Methanol/Blends	Same	Same tank as petrol/diesel

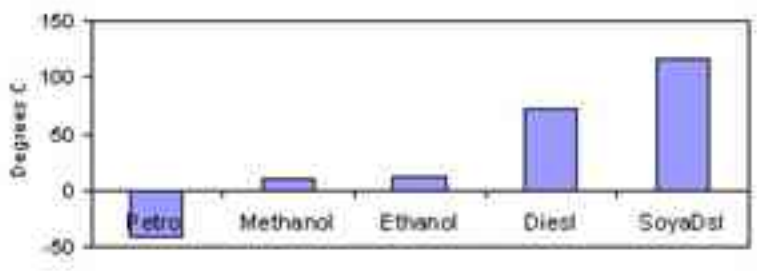

Fig-4: Flash Point Temperatures for Alternate Fuels

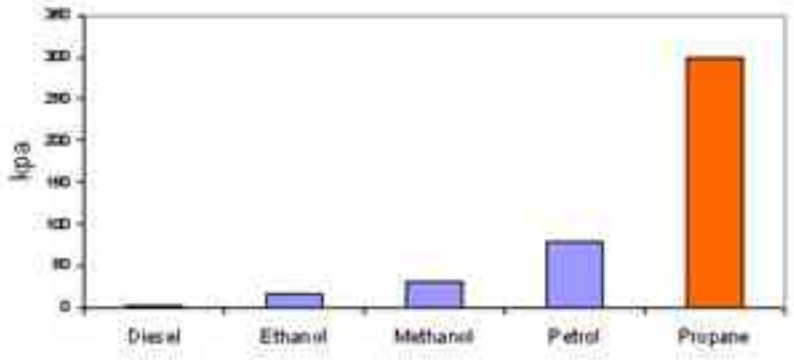

Fig-5: Fuel Volatility- (RVP @ 38 Degrees C)

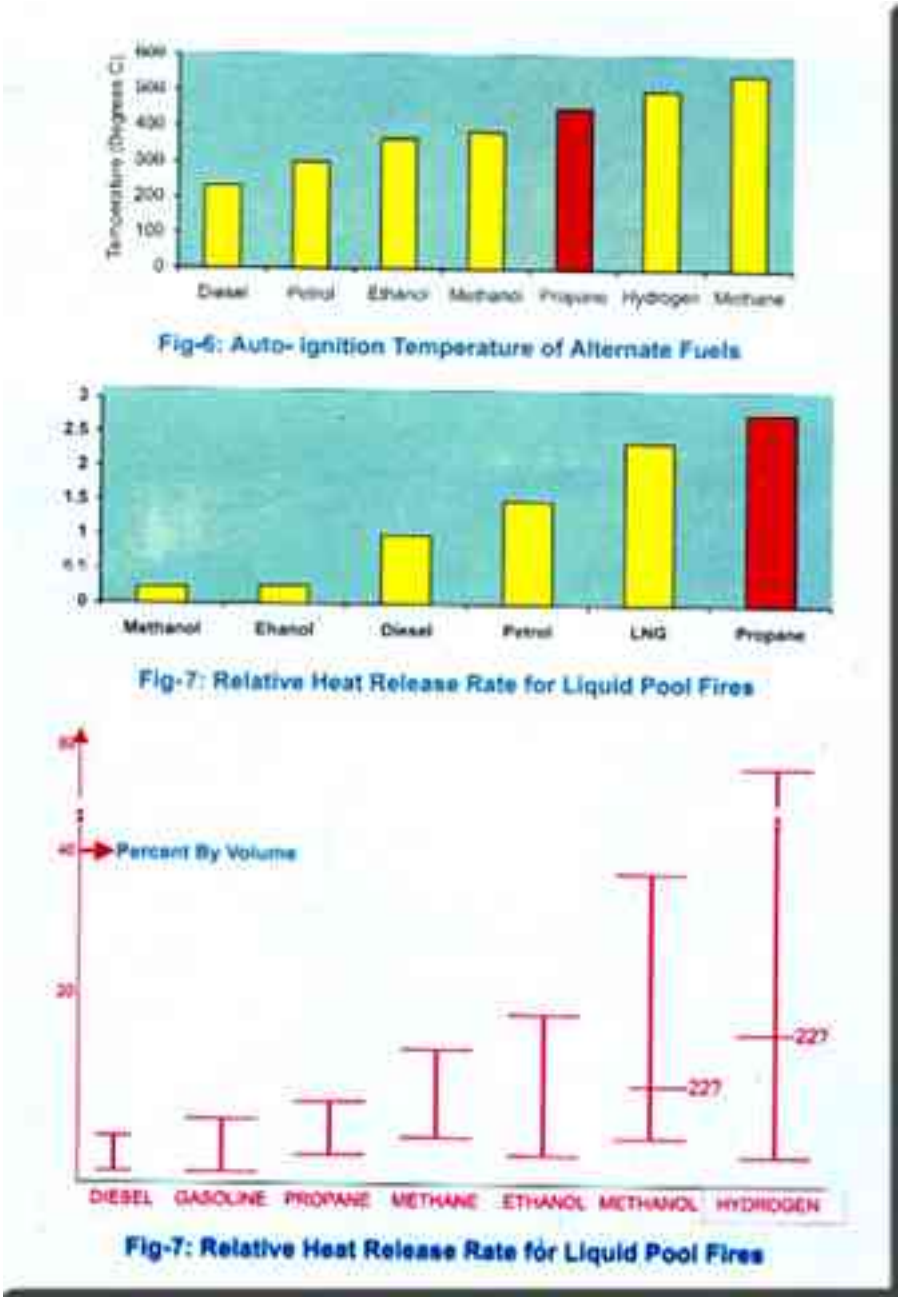

Fig-6: Auto- ignition Temperature of Alternate Fuels

Fig-7: Relative Heat Release Rate for Liquid Pool Fires

Fig-7: Relative Heat Release Rate for Liquid Pool Fires

Table-22: Representative Emissions from Various Alternative Fuels (g/bhp-h)-Heavy Duty Transient Tests

Fuel	PM	NOx	THC	CO	Toxic Wastes	Ozone Potential	Eqv. CO2-GHG

Diesel	2.000	4.60	0.750	2.00	0.005	0.80	342.2
Clean Diesel	0.050	4.60	0.175	2.00	0.05	0.70	368.0
MeOH(From NG)	0.035	2.25	0.275	0.50	0.05	0.65	400.9
CNG (Lean Burn)	0.050	3.00	1.200	0.35	0.00	0.40	285.5
CNG (Stoich)	0.025	1.40	0.730	1.00	0.00	0.40	302.2
LPG (Stoich)	0.050	0.90	1.050	7.00	0.00	0.65	384.2
EtOH(FromCorn)	0.050	5.00	0.500	0.50	0.05	0.80	229.1
LNG (Stoich)	0.025	1.38	0.730	1.00	0.00	0.40	499.7
H_2DI(Steam reform)	0.025	3.00	0.000	0.00	0.00	0.10	389.0
Pb-acid Battery	0.000	0.00	0.000	0.00	SO_2	0.10	307.7
PEM Fuel Cell (H_2)	0.000	0.00	0.000	0.00	0.00	0.10	207.5
Pb-acid Battery/CNG	0.013	0.70	0.365	0.50	SO_2	0.25	304.6
Pb-acidBattery/PEM- H_2	0.000	0.00	0.000	0.00	SO_2	0.10	257.2

Source: Hofeldt L.D.; "Alternative Fuel Technologies for Heavy Duty Vehicles:Performance, Emissions, Economics, Safety and Development"-Report to the French Government.

CONCLUSION & RECOMMENDATIONS

15.0 CONCLUSION & RECOMMENDATIONS

India has less than 0.4 percent of the world's crude oil deposits and rising oil imports are a major drain on the country's foreign exchange reserves. Expecting a steep rise in annual energy demand for power and transportation in the coming years, development of renewable energy technology options especially for the transportation sector has become a major thrust area now. The Government has been funding renewable energy programmes since the early 1980s. Parallel research and projects are being undertaken aiming at exploring alternative road transportation fuels but commercialization of various alternatative fuels still remains a dream though introduction of CNG happens to mark a step in the right direction.

The merits of alternate fuels are well recognized but fuel cost is very often perceived as the bottleneck for promotion of the fuel. Like any other new technology, cost of new fuel may be higher at the inception stage but as economies of scale exists for a product like auto-fuel, which caters to mass consumption, the cost factor smoothens with time making these fuels competitive with the existing one. Moreover, when the feedstock is domestic and renewable, it gives dividends by making the local market economy more vibrant. Therefore, any alternative fuels programme deserves greater Government support and will to succeed. Taking into account the feasibility, emission benefits and other logistics, the following issues may be considered for exploring any new alternative fuels in the country:

- The need for creation of a National Alternative Fuels Coalition (NAFC) is increasingly felt now. The coalition should have participation from all concerned agencies and ministries including automobile manufacturers, refiners, NGOs, etc.

- The long-term policy goals should be neutral to all types of vehicle fuels, both conventional fuels and alternative fuels. Fuel options may be many but choice of use should always be the users' preference.

- Availability of surplus conventional fuels outstripping the demand should not become a market barrier for introduction of alternative fuels.

- Pre-requisites like proper retail-fueling infrastructure, toxicological study of the fuels, demand supply logistics; legislative and regulatory formalities should be accomplished well in advance prior to lunching a new fuel.

- Temporary financial incentives for both the public and private sectors can help push the marketplace to develop an alternative fueling infrastructure and offer a greater variety of fuels for sale. Modest state financial incentives can potentially be justified by the energy security, risk reduction, trade balance, economic development, and environmental benefits that are possible from a greater use of alternate fuelled vehicles (AFVs). Various incentive approaches should be considered including incentives for alternative fueled vehicle purchases, retail fueling infrastructure and in-state production of alternative fuels. Should one or more incentive approach appear warranted, it should be justified by an analysis of estimated benefits and costs. Incentives should be temporary and discontinued after AFVs comprise a significant portion of the motor vehicle population.

- Some field trials with various alternative fuels already exist in India but most of the studies were conducted on old vintage vehicles. Considering the recent developments in technologies, it is recommended to carry out comprehensive field trials with new technology vehicles in Indian conditions. Institutes like IIP, IOC (R&D), etc. are capable of doing such studies and Government may avail funds to the concerned sectors for enhanced R&D in this field.

- Information dissemination with regard to the merits and demerits of alternative fuels play an important role in

promotion of the fuel. Intensive public awareness campaigns need to be initiated by the responsible institutions to educate the common public regarding the facts and myths of alternative fuels.

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