# 1 INTRODUCTION

## 1.1 Overview

The four-stroke, spark-ignition engine, in its current form, is arguably the single most technologically developed and optimised system of mechanical components in existence today.

While the principles governing its operation are identical to those that dictated the workings of the first internal combustion engine in 1886, the advances in engine design over the last century have metamorphosed the modern engine into a power source long bereft of the deficiencies of its predecessors.

However, despite enormous improvements and constant endeavours, there remains one fundamental problem in the operation of four-stroke engine; the fact that it generates waste products that are detrimental to the environment. Carbon monoxide and nitric oxides are of particular concern as they are toxic, and carbon dioxide is said to contribute towards global warming.

Government legislature and public concern over the past decades have resulted in ever-tightening emissions standards in almost all industrialized countries and most emerging economies. Thus, with these standards only likely to become even more stringent, there exists a need to find innovative ways in which these standards may be met.

With catalytic converters and unleaded fuel already being used in the drive for reduced emissions, the invention of yet another emission-reducing mechanical device, or chemically-enhanced fuel hybrid seems unlikely. In fact, car manufacturers are being forced to limit fuel consumption and hence, performance, in an attempt to comply with emissions standards.

However, an alternate solution presents itself; the development of a fuel capable of sustaining combustion within the spark-ignition engine without the production of its harmful by-products.

## 1.2 Alternate Fuels

Whilst the quest to find a viable alternative to conventional fossil fuels is definitely not a new undertaking, the resources and investment deployed in achieving this goal has certainly reached unprecedented levels.

The variety of fuels such as ethanol, methanol, natural gas, propane and biodiesel, that can now be classified as alternate fuels, according to the Energy Policy Act of 1992 of the United States of America, [1] serve as testimony to the efforts of the international community in addressing this concern.

Both ethanol and methanol are alcohol derivatives and are produced from the fermentation and distillation of starch crops, which have been converted into simple sugars [1]. They are used in the creation of E85 and E95, both of which are blends of ethanol and petroleum, E85 being 85% ethanol and 15% petrol and likewise with E95.

Emissions from the use of natural gas were found be to considerably lower as compared to conventional petrol. Reductions of up to 90% in carbon monoxide and 60% in nitrogen oxides respectively, were observed [1]. However, the feasibility of a long-term, large-scale, CNG-powered automotive fraternity is severely threatened by the relatively small quantities of natural gas available worldwide.

Other alternate fuels, such as electricity, are not completely independent of a chemical fuel source since their primary method of production involves the combustion of fossil fuels albeit at a distant power station and not within an internal combustion engine. While there are hybrid vehicles that run on regenerative electricity produced by the vehicle's engine under partial load conditions, such as Toyota's *Prius,* the combined life cycle environmental impact of these vehicles remains a contentious issue.

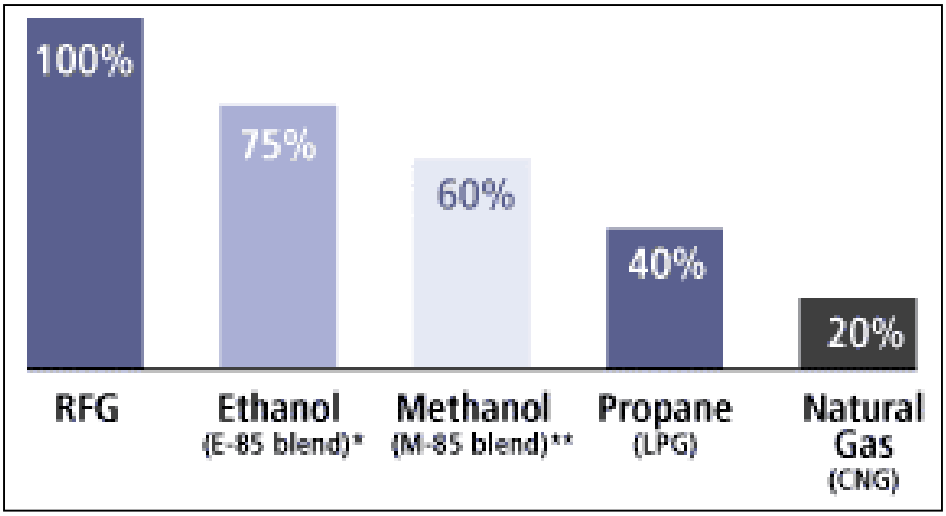


Figure 1.1: Comparison of Emissions [1]

The figure above indicates the percentage of combined nitrogen oxide ($NO_x$) and carbon monoxide (CO) emissions of each of the alternate fuels as compared to the emissions produced from reformulated gasoline (RFG), where the RFG emissions are taken as 100%.

It is clear that the emissions obtained from the use of natural gas are lowest, followed by propane, methanol and ethanol respectively. There does exist, however, another fuel source that, theoretically, should produce zero carbon monoxide and carbon dioxide ($CO_2$) emissions, seeing that its molecular structure is absent of carbon atoms. In fact, its by-product is nothing more than conventional water. Hence, the advent of hydrogen as a fuel source for automotive applications.

## 1.3 Hydrogen

Hydrogen ($H_2$) is the simplest and most abundant element known to man in that it comprises about 75% of the mass in the universe [2]. It is also found in all organic matter and is the primary constituent in water, which covers 70% of the earth's surface.

It comprises one proton and one electron and is the least dense substance, being 14 times lighter than air [2]. Hydrogen gas is also colourless, odourless and non-toxic. Thus, its production does not result in acid rain, depletion of the ozone layer or the release of harmful emissions into the atmosphere [2].

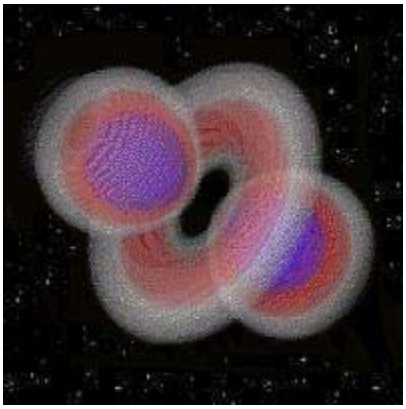

Figure 1.2: Energy field of the Hydrogen molecule [3]

Hydrogen is also the most efficient fuel as its combustion energy per kilogram is higher than that of any of the other conventional or alternate fuels. Hydrogen also produces 2-3 times more energy than other fuels upon combustion, since its lower heat of combustion value is greater than that of the other fuels [2]. Hydrogen properties may be found in Table 1.1 below.

**Table 1.1: Properties of Hydrogen [2]**

| | |
|---|---|
| **Chemical composition** | $H_2$ |
| **Boiling Point [°C]** | -252.7 |
| **Density @ 20°C [kg.m$^{-3}$]** | 0.08342 |
| **Higher Heating Value [MMJ.kg$^{-1}$]** | 141.9 |
| **Lower Heating Value [MMJ.kg$^{-1}$]** | 119.7 |
| **Auto Ignition Temperature @ 1 atm [°C]** | 520 |
| **Diffusivity [m$^2$.hr$^{-1}$]** | 1.697 |
| **Flame temperature [°C]** | 2318 |
| **Flammable range [%]** | 4-74 by vol in air |
| **Freezing/melting point [°C]** | -259.2 |
| **Heat of combustion by mass [kcal.kg$^{-1}$]** | 28670 |
| **Ignition energy [mJ]** | 0.02 |
| **Molecular weight** | 2.016 |
| **Specific gravity** | 0.0696 (air = 1) |
| **Specific volume [m$^3$.kg$^{-1}$]** | 11.99 |
| **Viscosity [kg.m$^{-1}$hr$^{-1}$]** | 33.84 x 10$^{-3}$ |
| **Volumetric energy density [kcal.kg$^{-1}$.mole$^{-1}$]** | 57.8 |

Therefore, from the arguments presented above, the feasibility of hydrogen as the next alternate fuel surpasses all other previously researched alternative fuels. In the quest to find a fuel capable of sustaining combustion within the internal combustion engine without generating any of its undesirable emissions, hydrogen seems to be the answer.