Title: ALTERNATE ENERGY SOURCES FOR CI ENGINES: A FOCUS ON NIGERIA

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ABSTRACT

The supply of energy through sources that have been adjudged not to be amenable to cleanliness and supportive of emission control, which are also finite, necessitates the search for alternative sources of energy. This becomes particularly important for transportation, specifically Internal Combustion Engines. It is also applicable to developing countries like Nigeria, which have the desire to develop technologically and would benefit from alternative technological paths to ensure the development, deployment and utilization of environmentally friendly technological products. Nigeria, a country rich in oil resources, would benefit from proper study and development of alternative products, specifically Compressed Natural Gas, which she has in abundance. CNG has shown a variety of capacities and adaptability, which makes it suitable to address endemic problems such as emissions, energy efficiency and thrift of conventional fuels like Gasoline and Diesel. It then becomes imperative that the pace of development and deployment of CNG consuming engines be fast-tracked. In this research, we hope to facilitate this process by comparing alternative power units, CNG units with conventional gasoline units. And also we hope that by employing the design principles and other factors that have made gasoline vehicles dominant in the passenger vehicle market, we shall arrive at an efficient and reliable CNG-powered solution for passenger vehicles.

Keywords: Energy, Engines, Emissions, CNG, Gasoline

Introduction

The serious campaign for alternative energy sources began when tougher emission standards and sanctions were set and imposed, and also as it became apparent that energy conservation is also as important as clean air. Fossil fuel sources are finite, no matter how long the current exploration for them lasts. Besides, their poor rating on emission issues highlights the need to begin to think of alternatives.

Nigeria is rich in oil resources. This therefore leads to a very strong interest in alternative fuel products (particularly Compressed Natural Gas-CNG), an alternate fuel that has shown a multitude of capabilities and adaptability to address endemic problems such as emissions, energy efficiency and thrift of conventional fuels like gasoline and diesel. These endemic problems are the areas of serious worries to the world.

The main objectives for technical developments have varied and have been approached from different perspectives. For, example, the main force behind the Western nations' strategy for automotive developments has been emissions controls and lately, fuel economy. The genesis of all this can be traced to the U.S. when in 1965 the U.S. government using the environmental Protection Agency (FEPA), imposed pollution control laws, in realization of the significant impact increase, car population has had on the environment (M.L. Monaghan, 1988),. Significant advancement has been recorded in engine technology and fuel quality in the last two decades. This has been made possible by the new focus on fuel economy which has led to renewed interest in diesel engines and lately, CNG engines.

Reducing fuel consumption of automobiles is an area that has continuously engaged the attention of the world in automotive development, fuel efficiency vis-à-vis development of environmentally friendly products will continue to be the central focus of any meaningful engine development as vehicle engineering continues to grow in complexity. Technical advances available in developed countries provide technological options that can be adapted to facilitate radical transformation of existing facilities in Nigeria, or that may lead to a rapid transformation of her developmental strategies. But the scope and enthusiasm with which to achieve these potential improvements are crucially dependent on appropriate governmental actions by way of legislation and the towing of a technological path that can take advantage of her abundant energy resources.

Nigeria is a major producer of natural gas. Her proven capacity is put at 20 billion cubic metres by NEST (1992). The capacity could have been more but the rest was simply flared due to lack of appropriate processing technology. An authoritative source, Nigerian Environmental Study/Action Team (NEST, 1992) has estimated that the natural gas reserve will last for the next 138 years. What we have even witnessed so far in gas development is only incidental to oil production since serious gas exploration is yet to commence in earnest.

Methodology

A review of engine principles that have brought gasoline engines great fortunes in developed countries is done to see to what extent these principles or concepts can be adapted and applied to support:

A very strong proposition for alternative energy sources to gasoline to be used in CI engines. This position is canvassed from Nigerian point of view and is based on its compatibility with:

1. Modern engine designs vis-a-vis engine performance in terms of emissions, efficiency and thrift
2. Its form, availability, refining process, characteristics and implications

In order to achieve overall low fuel economy, low maintenance, low costs, and longer service life.

CRUDE OILS

The fact is, the radical revolution vehicle engineering has undergone due to technological advancement in the last two decades has had tremendous influence on fuel quality, engine development and performance. Crude oil quality is usually assessed by volume. A U.S. barrel of 42 U.S. gallons is now the standard measurement quality, although hitherto those in the Far East used U.K. gallons and in Japan the Kilolitre (D.C. Ion, 1980). Crude oil quality, which is one of the most important characteristics in determining its ranking in world oil markets, is assessed in a number of ways. It is either expressed as specific weight on a standardized scale determined by API (American Petroleum Institute), or as specific gravity numbers. The quality is usually assessed by the degree of lightness, which is higher for gasoline. Usually, their nature is determined whether they are naphthenic (closed-chain, above C_5), or paraffinic (straight-chain). Another important assessment of the quality is done by determining the degree of impurities, usually on the basis of the sulphur content expressed as a percentage by weight.

Gasoline and Diesel Fuels

The two most important fuels processed from crude sources by oil explorers are Gasoline and Diesel fuels. These two fuels have enjoyed enormous patronage in automotive industries, largely because they are the most convenient sources of energy for use in internal combustion engines. The percentage of these quantities derivable from crude sources is put at between 30% and 70% (K. Owen and T. Coley, 1990). Their steady growth in quality and refinement over the years has been driven both by increasing demands from users for more performance and by emissions regulations becoming tighter in most countries, particularly in Western Europe and the U.S. These two fuels differ from each other significantly even though diesel fuel is obtained from the conventional distillates which are intermediate distillates to gasoline. Their compositions and viscosities account for this, even though they may be from the same source.

The above demands constrained oil explorers to work towards producing fuel that burn well. The engine designers on the other hand are also constrained to ensure that their production vehicles run satisfactorily on these fuel qualities.

In order to ensure strict compliance, governments set legislative requirements for the oil industries in what is known as ‘national specifications’ in individual countries. These specifications summarise the fuel parameters that influence vehicle performance in terms of emissions, power output and fuel economy. To ensure that uniform practice applies throughout the world and for the engine designers’ products to satisfy these stringent legislative conditions in terms of the above requirements, special legislative fuels and reference fuels were formulated. These are known as standards and serve as references for those in exploration and processing industries. They apply globally and are generally quite different from national specifications. The objectives of the two categories of legislations can be clearly distinguished. The standard legislation that applies to the motor industries is set to achieve the following objectives:

i. Legislative fuels are used for certification purposes and represent the average fuel qualities that can be found in most countries.

ii. Reference fuels are used for engine development purposes.

In addition to (i) above, these baseline fuels also represent qualities close enough to the poorest qualities that may be sold in any particular place for whatever properties such as volatility or cetane number.

Gasoline

Gasoline is distilled in proportionate blends consisting of volatile hydrocarbons whose main components range between C_5 and C_{12} , and have properties that average those of octane, C_8H_{18} (C_nH_{12n+2}) , i.e., the paraffinic family (alkanes), which may be straight-chain or branched-chain configuration molecules. These are examples such as methane; CH_4, ethane; C_2H_6, propane; C_3H_8, and C_8H_{18}, which may be n-octane or Iso-octane. The boiling points of these blends are between 30^0C and 200^oC, and they have relative densities of about 0.74 (E.M. Goodger, 1980).

Diesel Fuel

For the purpose of brand identification, it is darkish-brown in colour (E.M Goodger, 1980). It is denser than kerosene with a relative density of 0.87. It is used in the heavier and larger diesel engines used in big ships and industrial installations. These applications are critical in quality and particularly as diesel burns well in low speeds engines.

CNG (Compressed Natural Gas) Engines

The two conventional fuels that have undoubtedly dominated fuel usage in automotive industries are gasoline (petrol) for SI-engines and diesel (gas oil) for CI-engines. These are the two fuels that have been developed to the generally satisfactory standard for the sort of performance desired in the motor industries, and they are convenient for use. This is the way development has gone at least the past two decades. Judging by the current state of our petroleum reserves (now put between 30-40 years more), U, Seiffert and P. Waltzer (1990). Between then and now new oils have been found, which have put Nigeria proven reserve at between 30-45 billion bbl and to last the next 45 years if no new oil was found (http://en.wikipedia.org/wiki/Oil_reserves_in_Nigeria). Various alternate fuel sources have been proposed and some are actually being test-run. The attraction of CNG fuel is in its low emission levels and low cost, according to a recent review study conducted by Semin et al (2009), CNG has favourable emissions outlook compared to other alternative fuels as shown in the table below.

Pollutant	Natural gas	Oil	Coal
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulphur Dioxide	1	1,1222	2,591
Particulate	7	4	2,744
Mercury	0.000	0.007	0.016

Table 1**:** Fossil Fuel Emissions Levels – Pounds per Billion Btu of Energy Input

Source: Energy Information Administration (1998). Natural Gas Issues & Trends, www.eia.doe.gov.

In comparison, Compressed Natural Gas (CNG) is a fossil fuel gotten from same source as gasoline (petrol), diesel, or propane/liquefied natural gas (LPG). Like gasoline and diesel fuels its combustion produces greenhouse gases; however it is more environmentally friendly and much safer to handle than these other fuels. For example, in the event that it pours, since it is lighter than air it disperses quickly into air. Also another advantage of this gas is that it can readily mix with biogas (another gas gotten from sources like dumpsites or waste water) which does not in any way increase the concentration of carbon in the atmosphere.

CNG is a compressed natural gas which is composed mainly of methane (CH_4) and occupies less than 1% of the volume of standard atmospheric pressure, and is usually stored and dispenses in hard cylindrical, or spherical shaped containers at a pressure between 200-248 bars. CNG lends itself readily to use in traditionally convertible engines (bio-fuel engines-gasoline/CNG). CNG vehicles are being predominantly used in traditional vehicles like pickup buses, trains, tuk-tuks, transit and school buses in Asian-pacific regions of the world, particularly Pakistan (as can be seen later in statistics), also in Latin America, Europe and North America due to high fuel prices and environmental challenges. However, it is not a success story all the way due to high conversion costs. The main reason why use of CNG fuel is dominating in the vehicles mentioned above, is because they can readily amortise investments on them and are also (CNG fuels) cheaper compared to these other fuels. Inspite of these challenges, CNG is making a steady progress of about 30% growth rate annually (http://www.nlng.com/publications/NLNG%2off%2012.pdf) retrieved on 04/09/2012, time 12.30 pm.

Volumetric energy density of CNG fuels is high compared to these other fuels because it is not stored in liquid form. It is estimated to be 42% of LPG, 25% of diesel(http://www.chevron.com/deliveringenergy/naturalgas/?utm_campaign=Chevron_Africa_.)

Table of World Vehicles Population (in the order of hierarchy)

Serial Number	**Country**	**Vehicle Population (M)**	**Number of Fuelling Stations**
1.	**Iran**	**2.86**	**1800**
2.	**Pakistan**	**2.85**	**Information not available**
3.	**Brazil**	**1.7**	**1,704**
4.	**India**	**1.1**	**Information not available**
5.	**Italy**	**0.78**	**800+**
S6.	**People's Republic of China**	**0.61**	**Information not available**
7.	**Colombia**	**0.36**	**460**
8.	**Uzbekistan**	**0.31**	**Information not available**
9.	**Thailand**	**0.30**	**Over 400**
World Total		**14.8**	

Table2

Source: http://www.chevron.com/deliveringenergy/naturalgas/?utm_campaign=Chevron_Africa_.)

The table above shows that Asia-Pacific is leading the pack with 5.7 M, closely followed by Latin America about 4 M. Although information on the number of filling stations so far developed by others in the table is not readily available, it is clear that this development programme is being vigorously pursued in a number of countries as this table shows.

Other Proposed Alternative Fuels

Some other alternative fuels have actually been developed and are on trial run. For example, Methanol (M85) blend programme made up of 15% methanol and 85% gasoline was investigated in Germany as far back as in the 1970s (U. Seiffert and P. Waltzer, 1991). This was intended to reduce the dependence of Germany on imported oils. Hydrogen is another alternative fuel that has been acclaimed as having great potentiality. An experimental hydrogen vehicle, in which a gasoline engine was modified to run on hydrogen fuel has been built by Daimler and BMW (U .Seiffert and P. Waltzer, 1991). Although an optimistic view of hydrogen vehicle design has been put forward, the energy balance outlook does not look so good. In a rough estimate by U. Seiffert, the price of liquid hydrogen is about 2.0DM per litre (where 1 dollar = 1.7DM). This is very expensive compared to petroleum fuels selling currently at 5.1DM equivalence (hydrogen is about $3.00 per gallon of gasoline). Moreover, based on this analysis, for the same amount of energy, one will require three times as much hydrogen as gasoline. This has serious implication for storage requirements.

Rape oil is another alternative fuel that has a renewable energy carrier capability. A development programme similar to that developed by Daimler and BMW, has shown rape oil to be a very good alternative to diesel, with slight modifications to a diesel engine being necessary (U. Seiffert and P. Waltzer, 1991). Other alternative fuels that are being further investigated are pulverized coal, synthetic gasoline and use of nuclear energy in electric-driven vehicles. But on the whole, a lot still needs to be done in order to develop them to the standard satisfactory for along-term application. It is still very difficult to think that these alternatives will completely displace the conventional fuels in the foreseeable future. There is yet no feasible single replacement for the conventional fuels. What may possibly happen is that certain alternatives will be dedicated to specific applications, for example, operations in urban transportation, or inter-state commuting from a Nigerian point of view.

According to E.M. Goodger, 1993, the "likely long-term approach may be to develop alternative fuels that will bear little similarity with conventional fuels, or their sources". These are such fuels as hydrogen fuels, liquefied hydrocarbons (HC), such as methane and propane, bio-carbohydrate $C(H_20)$, nitro hydrocarbon (HCNO), such as nitro methane, nitro hydride (HN), such ammonia and hydrazine (E.M. Goodger, 1993). One alternative, which is currently happening as a short-term approach, is to augment the conventional fuels by developing alternative fuels that is used along-side conventional fuels and would be available in considerable quantities after exhausting the life-span of current reserves. Examples of such are the current bi-fuel systems (LPG/gasoline and CNG/gasoline).

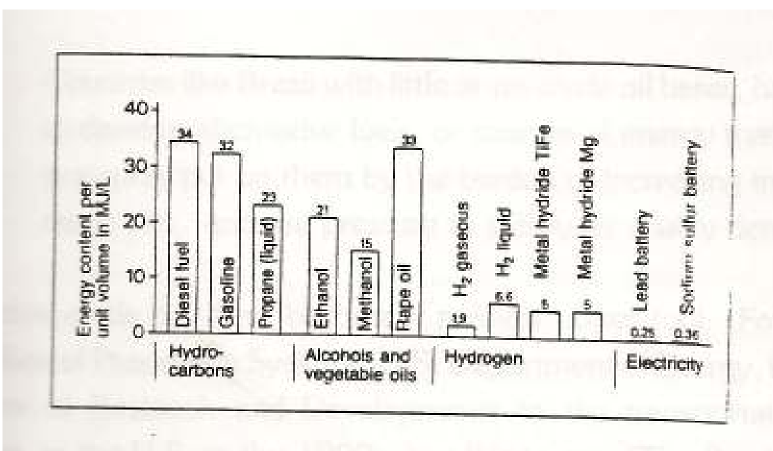

Figure 1:	Energy content per unit volume of various energy carriers suitable for vehicle propulsion.

Source:	U. Seiffert and P. Waltzer (1991)

The graph above shows that the traditional energy carriers, i.e., gasoline and diesel fuels are very much in contention in terms of energy contents per unit volume in MJ/L suitable for vehicle propulsion particularly in Nigerian context where long distance commuting is a necessity in the absence of a well developed public transportation system. Apart from rape oil that compares favourably with these traditional fuels, a lot still need to be done on other alternative energies if they hope to displace gasoline and diesel in the foreseeable future.

Fuel Characterisation

CNG is composed of many components (gases – inert, cetane, nitrogen and CO_2) , out of which methane is a major component ranging in concentration between 80 to 99% (SAE SP-958, 1993). CNG has no fixed composition as it varies from source to source. Its fuel characteristics are determined through a parameter known as Wobbe Number (A. Unich et al, SAE-930929), as reported by (SAE SP-958, 1993). The Wobbe Number of CNG is computed by dividing the higher volumetric heating value of CNG by the square-root of ratio between CNG air specific gravity i.e., this is shown to represent the energy flow rate which results from a certain pressure drop. Wobbe Number increases in magnitude as the non-methane components increase. This means the Wobbe number too varies as the sources of CNG do. One attraction of CGN in environmental terms is that its combustion produces less CO_2 (about 25%O, SAE SP-958, 1993), than diesel and gasoline at the same engine efficiency. So it is no surprise why campaign for its global use has been intensified especially by IEA (International Energy Association), as a result of this significant contribution to greenhouse effects.

CNG however, has a lower fuel density in comparison to diesel and gasoline fuels and as a result has poor volumetric efficiency. This results in low heating value at stoichiometric air-fuel ratio which compares well with that of gasoline but CNG-air mixture is about 10% lower than gasoline (SAE SP-958, 1993). Anyway this is not considered as a big problem since its higher octane number allows the use of higher compression ratio and the consequent improved thermal efficiency.

Storage System

CNG, as already shown can only be stored in cylinders as compressed gas at a pressure 0f 220 bars (3150 PSI). This is a volumetric content of 8.0 MJ/l, in stored condition, about 75% and 78% less than gasoline and diesel, respectively. The effect of this, combined with the weight of the cylinders make CNG's use for passenger cars unattractive, as the travelling range and load carrying capacity are significantly affected. The weight problem can be appreciated when a simple calculation is done. The comparison is done by dividing the mass of the fuel and tank by the energy content of the fuel. The significance of this for CNG in terms of fuel and tank mass per energy unit is a function of gas containers.

Carburettor System

The CNG carburettor is similar in construction (mechanical) to the type used in conventional gasoline engine. Two types of carburettors to-date are available – the fixed throat and the variable throat types. Since CNG is usually stored in compressed form in cylinders, it must be passed through a three-stage pressure reducer before being fed to the carburettor at atmospheric pressure. In the fixed throat carburettor type, the main adjusting screw located between the pressure reducer and the carburettor enables the air-fuel ratio to be set. In the variable throat type, the membrane is located within the vacuum chamber and connected to the gas metering valve at its outer end. The depression created by the in-coming air supply activates the membrane, while the metering valve controls the fuel supply. However, these two carburettor systems are not able to supply accurate air-fuel equivalence ratio which is a crucial requirement for low emissions. In view of this limitation, some CNG carburettor systems are designed to operate with closed-looped-sensor control system. Alternatively, an electronic fuel-injection system actuated by electromagnetic actuator can be used with CNG-gasoline engine with better fuel metering control.

Safety Requirements

CNG has an extensive safety testing device programme. This has been neatly put together in Italy, a country reputed for her versatility and vast experience in CNG resource programme. The test for safety is very rigorous and it is done at both manufacture and at subsequent intervals during actual use of some pressure of 2.5 times the service pressure (SAE paper N. 830267, 1993, SAE paper N. 831078, 19930). CNG in use and handling is considered safe as a result of its lightness compared to air. In the event of CNG leakage, there is no danger of fire associated with it since it goes upwards and disperses quickly. Unlike gasoline vapour and other gaseous fuels which require longer time to disperse leading to the spread of danger far away from the source of leakage.

Emissions

Information on CNG emissions is sparse and not comprehensive. However, in general particulate emissions are very low. Other emissions are more dependent on combustion system arrangement. Also HC emissions are largely methane and this gas is not toxic, so it is not a serious concern. CNG engine works well with lean-burn engine operation strategy since it produces low NO_x level, and because of its good tolerance to combustion dilution and proper air-fuel mixing. Another attraction of lean-burn application to CNG engine is its tolerance to the use of higher compression ratios. The reduced tendency to knocking of CNG fuels, results in the use of higher compression ratio viz-a-viz improved thermal efficiency and favourable exhaust temperature. This further leads to design for durability and longer service life. Part-load operation is an area of serious problem to gasoline engine operation with its attendant pressure losses. This is reduced in CNG engines as a result of lower charge energy.

From our combustion experience, a major influence on engine emissions is the air-fuel ratio and this is why its control is very crucial especially in conventional (gasoline) internal combustion engines. Therefore, the various types of CNG, for example, (SI lean-burn, SI stoichiometric and CI dual fuel), displaying different emissions characteristics, will be a panacea to this problem. Emissions of major regulated pollutants such as NO_x, CO and HC from internal combustion engines are the current concern of the public. For example, in comparison, CNG is essentially Methane (CH_4) with a calorific value of 900 kJ/mol, which burns with oxygen to produce 1 mol of CO_2 and 2 mol of H_2O, while gasoline which is regarded essentially as benzene, or similar (C_6H_6), has a calorific value of 3,300 kJ/mol, burns to produce 6 mol of CO_2 and 3 mol of H_2O ((http://www.chevron.com/deliveringenergy/naturalgas/?utm_campaign=Chevron_Africa_.). This clearly shows that for every mol of CO_2 produced, CNG releases over 1.6 times as much energy as that released by gasoline (or for the same amount of energy burnt, CNG produces 40% less of CO_2). As can be seen, CNG is less pollutant but more efficient emitting significantly less of CO_2, unburned hydrocarbon, (UHC), CO, NO_x, SO_x and particulate matter compared to gasoline. For example, an engine running on gasoline for 100 km emits 22,000 grams CO_2, while covering same distance, CNG emits only 16,275 grams of CO_2 ((http://www.chevron.com/deliveringenergy/naturalgas/?utm_campaign=Chevron_Africa_.).

Conclusion

The author is advocating that energy use be regionalized judging by the trend of events so far i.e. different regions of the world should be encouraged to develop indigenous energies, of course since the composition of this gas varies from source to source, in order to prevent the formation of new dependencies. Each region should identify alternate energy source that she is rich in and utilize it by producing vehicles that are adaptable to such energy. For example, Nigeria is rich in petroleum resources and therefore has gas in abundance. This option is feasible; therefore, the world and Nigeria should chart alternate energy solution along this path.

Developments in fuels and engines have invariably progressed in parallel. Advancement in technology in either of these areas has permitted and demanded a corresponding improvement in the other. The picture we have seen of fuels and engine developments over the years has provided an understanding of the changes that have taken place concurrently in fuel quality and engine performance. In advanced countries, development will continue to focus more on high fuel quality in order to meet the high performance demanded by customers while still meeting the increasing demand of legislation.

The sparseness in CNG vehicle development clearly shows the dominating role oil fuels are still playing in automotive activities. Very few CNG dedicated vehicles have actually been developed and are still being test-run. This goes to show that a lot still needs to be done to develop it to acceptable standards. What we have witnessed so far is a conversion programme in which the existing diesel and gasoline engines have been converted to run on natural gas. The success of the entire conversion programme has been quite straightforward with gasoline engines which only require additional gas conversion kits, a mixer, control valves and regulators. For the diesel engines, the necessity for bi-fuel systems and the complications involved with carrying two fuels with separate fuel lines that run in parallel, have made conversion less straightforward.

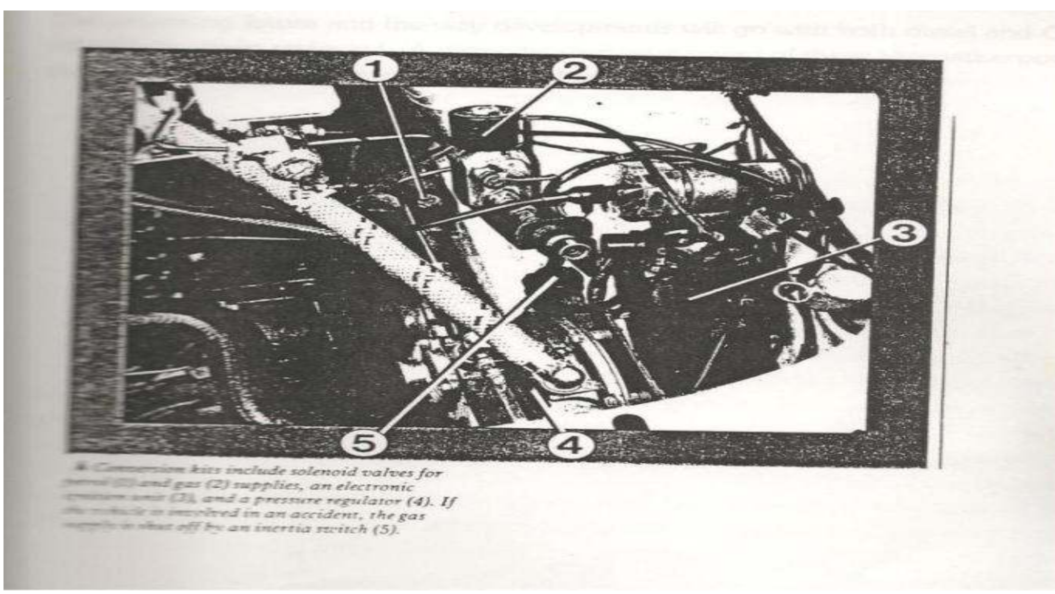

Figure 2: Conversion Kits and Fuel Supply Systems for CNG Vehicle

Source: Aspect Magazine (1992)

This is necessary because CNG fuels require higher pressure and temperature than diesel to self-ignite; therefore, diesel fuel is used as a starting aid for the engine. Since these engines are not designed to run only on natural gas, power outputs from them are far below what they would have usually produced if they were to run on conventional fuels. The implication of this is that their efficiency is decreased by about 10% (M. Cunningham, Motor Transport, 1992).

Although CNG engines have shown greater qualities and good operational characteristics than gasoline engines, improved thermal efficiency, and higher operational safety, they are still undergoing transitional stages and still require huge investment in monetary terms as well as expertise inputs to develop them to a satisfactory standard for its commercial application to passenger cars. Experience and technology for CNG engines vary with less developed countries still understudying those countries with vast experience. For example, U.K. and Italy have cooperation programme.

Recommendation

It is only being reasonable to start now to think of a gradual transition to a more sustainable future energy scenario. The earlier we start considering any possible future replacements, the better for automotive developments. This is in view of the uncertainty surrounding the future of crude oil supplies. Concerted efforts have so far been made to put into working out possible future replacements for the two conventional fuels, while being mindful of the implications of such replacements. This is in view of the concern for the environment, amongst other things. Care should also be taken not to create another dependency.

CNG engine development programme is promising for countries that have indigenous reserve of natural gas and capability to exploit it. A CNG conversion programme is only recommended as a long-term solution for Nigeria in consideration of many issues, amongst which economic factors and technical-know how are chief.

On emissions, Nigeria should not take the position that emissions are part of development. It should be recognized that emission problems created by the used cars imported into the country are enormous. Their regulation can only be effectively enforced if the government can back the Federal Environmental Protection Agency (FEPA) with action.

It is recommended that Nigeria should invest and focus more on R & D, especially in the area of vehicle engineering development and massive training of her citizens, as a way of promoting technology transfer.

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APPENDIX

Gas storage in a car.

A CNG powered high-floor Neoplan AN440A, operated by ABQ RIDE in Albuquerque, New Mexico.

CNG pumps at a Brazilian gasoline fueling station

Main article: [Natural gas vehicle]

CNG station in Rosario, Argentina.

A CNG powered Volvo B10BLE bus, operated by SBS Transit in Singapore.

CNG powered bus in Italy

North America

The Honda Civic GX is factory-built to run on CNG and it is available in several U.S. regional markets.

Source: http://en.wikipedia.org/wiki/Compressed_natural_gas retrieved 02/07/2012 time: 11:20 am.