COMPARATIVE ECONOMIC ANALYSIS OF COMPRESSED NATURAL GAS AND AUTOMOTIVE GAS OIL AS AUTOMOBILE FUELS

BY:

UBANI, UZODIMMA BYRON (B.ENG.)

REG. NO: 20094759278

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CERTIFICATION

This is to certify that this thesis was done by **Ubani Uzodimma Byron**, in partial fulfillment of the requirements for the award of Master of Engineering (M. Eng.) in Petroleum Engineering.

Thesis Supervisor (Dr. C.I.C Anyadiegwu)	29/6/15 Date
HOD, Petroleum Engineering (Dr. C.I.C Anyadiegwu)	29/6/15 Date
Dean, School of Engineering (Prof. E.E Anyanwu)	29/06/2015 Date
Dean, Post-Graduate School (Engr. Prof. K.B Oyoh)	Date
Prof. E.S Adewole External Examiner	29-06-2015 Date

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ABSTRACT

Comparative economic analysis of the use of compressed natural gas (CNG) and the use of AGO for power generation was presented. The data for costs of constructing and running CNG-powered vehicles were obtained for the study. Separate economic analyses of running the CNG-powered vehicles and running AGO vehicles were performed. The initial capital cost for CNG project amounted to N4.31 million and that for diesel was N3.60 million while the annual operating cost for CNG is N1.47 million and that for diesel is N2.98 million. This difference in the capital costs is basically due to the addition of the extra parts and connections to convert the AGOl-powered vehicle to a bi-fuel-powered vehicle which would be able to use CNG as fuel. The difference in the operating costs is due to the fact that the costs of the two fuels are not the same. The net revenue for CNG is N2.85 million while that for diesel is N1.34 million. This difference in net revenues is resultant from the difference in their gross revenues resultant from the difference in operating costs. Figures in the text were used to determine the pay-out of the projects which is 1.45 years for CNG and 2.7 years for diesel respectively. The NPV and other parameters that make up the project economics were estimated for CNG and diesel. The NPV for CNG at an expected rate of return of 10% is N17.56 million while for AGO, the NPV is N5.86 million. The summary of the result of the calculations of all the parameters examined for both CNG and diesel was also presented. From the whole analysis done it is easily seen that using CNG for powering vehicles is more profitable than using AGOl.

Key Words: Compressed natural gas, diesel, economic analysis, NPV, pay-out, IRR, automobiles.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

Natural gas, a fossil fuel comprised mostly of methane, is one of the cleanest burning alternative fuels (US DOE, 2013). According to CEC, (2013), most natural gas comes from three types of wells: natural gas-and-condensate wells, oil wells, and coal bed methane wells. In 2003, California had over 1,200 natural gas-and-condensate wells operating. Well-extracted natural gas requires a cleanup process before it can be used in vehicles or residences.

Taking USA as an instance, more than 99 percent of the natural gas used in the United States comes from domestic or other North American sources. However, increasing demand for natural gas in power plants will require new supplies from non-North American countries, increasing dependence on foreign sources of energy. The Energy Information Administration (EIA) predicts that, by 2025, more than 15 percent of USA natural gas supplies will be imported from countries other than Canada and

Mexico. Fig 1.1 below shows the consumption of natural gas for vehicles in the US between 1996 and 2005.

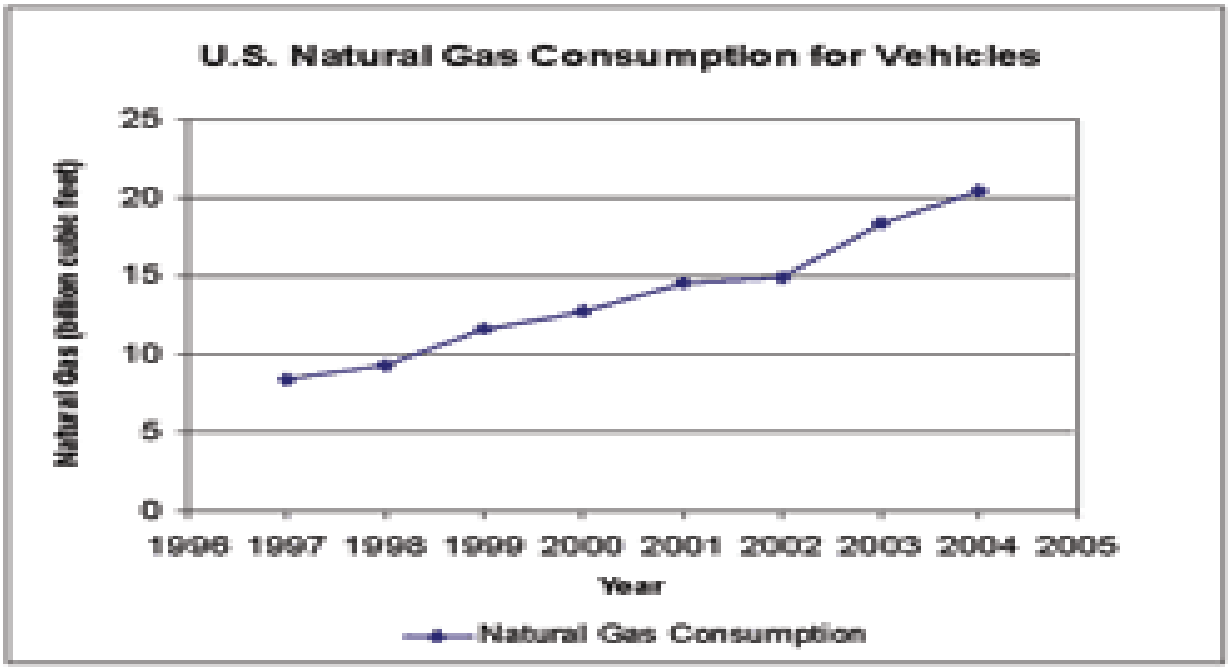


Fig 1.1: US Natural Gas Consumption for Vehicles from 1996 to 2005 Source: CEC, (2013).

Natural gas can be used in the form of compressed natural gas (CNG) or liquefied natural gas (LNG) to fuel cars and trucks.

Dedicated natural gas vehicles are designed to run on natural gas only, while dual-fuel or bi-fuel vehicles can also run on gasoline or diesel. Dual-fuel vehicles allow users to take advantage of the wide-spread availability of gasoline or diesel but use a cleaner, more economical alternative when natural gas is available. Since natural gas is stored in high-pressure fuel tanks, dual-fuel vehicles require two separate fueling systems, which take up passenger/cargo space.

Natural gas vehicles are not available on a large scale in our present era — only a few models are currently offered for sale. However, conventional gasoline and diesel vehicles can be retrofitted for CNG (CEC, 2013).

1.2 STATEMENT OF PROBLEM

The need to pursue the development of alternative automobile fuel other than PMS and AGO in Nigeria is based on the following associated problems:

- The rising cost of refined petroleum products, such as PMS and AGO
- Environmental pollution caused by PMS and AGO exhaust fumes.
- Perennial scarcity of PMS and AGO due to the poor state of Nigerian refineries.
- The maintenance cost of using an AGO-powered vehicle

1.3 OBJECTIVE OF STUDY

This project is aimed at contributing to the assessment of the need for the use of CNG in transportation systems. The major objective of this research is to compare the economic analysis of compressed natural gas and automotive gas oil as automobile fuels.

The specific objectives of this work are:

- **To show the conversion of AGO-powered vehicle to CNG-powered vehicle for transportation in Nigeria**
- **To show the economic viability of using CNG over AGO as automobile fuels in Nigeria**
- **To improve the awareness in the use of natural gas as automobile fuel instead of depending only on PMS and AGO**

1.4 JUSTIFICATION OF STUDY

Overtime there has been some level of scarcity of refinery fuels like PMS and AGO in Nigeria. Although this does not occur at all times but it has led to the general increase in the cost of these fuels for drivers whose vehicles make use these refinery liquids as fuels. Thus the need for the invention of an alternative fuel has sprung up.

Study is conducted in this research work on the use of CNG as that alternative fuel to supplement the refinery fuels for use in transportation.

Various analyses involving economic and operational analyses have been made regarding the introduction of CNG for use in automobiles in Nigeria.

1.5 SCOPE OF STUDY

This research work covers the fundamental study of the evaluation of the use of CNG for automobiles and the possibility of the conversion of already made diesel-powered vehicles to CNG-powered vehicles.

The scope of this work centers on the use of CNG as vehicular fuel in Nigeria with emphasis on the economic analysis of the use of CNG compared to the use of diesel in the transportation system.

CHAPTER TWO

LITERATURE REVIEW

2.1 BACKGROUND STUDY OF COMPRESSED NATURAL GAS

Natural gas is one of the cleanest, safest, and most useful forms of energy in our day-to-day lives. Natural gas is a hydrocarbon, which means it is made up of compounds of hydrogen and carbon. The simplest hydrocarbon is methane; it contains one carbon atom and four hydrogen atoms. Natural gas can be found by itself or in association with oil. It is both colorless and odorless. While mainly methane, the other hydrocarbons include ethane, propane, and butane. Water, oil, sulphur, carbon dioxide, nitrogen, and other impurities may be mixed with the gas when it comes out of the ground. These impurities are removed before the natural gas is delivered to our homes and businesses. The fact that natural gas is combustible and burns more cleanly than some other energy sources helps reinforce its position as one of the most highly used energy sources. Energy yielded by natural gas can be measured in a variety of ways, and the most common is the Gigajoule (GJ), which is one billion joules, the metric measure for heat or energy (Go Natural Gas Inc., 2009).

Natural gas is a fossil fuel, meaning it originates from the remains of plants and animals that lived many millions of years ago. These organisms were buried and exposed to heat as a result of being highly compressed underneath thousands of feet of soil and rock. These forces transformed the once living organisms into natural gas. Natural gas is found in reservoirs beneath the surface of the earth. Large layers of rock trap the natural gas as it tries to float to the surface. Once removed from the underground reservoir, the natural gas is usually transferred to a gas processing plant to remove impurities and by-products. After being processed, the clean natural gas (almost pure methane) is transported through a network of pipelines and delivered to its point of use, including our homes.

There are three main types of transportation pipelines: gathering, transmission, and distribution pipelines. Gathering pipelines transport raw natural gas directly from the wellhead to the gas processing plant. From the plant, the highly pressurized natural gas is gathered into increasingly larger pipelines, almost always underground, until it reaches the large transmission pipelines where it is often transported over large distances. From the transmission pipelines, the gas flows into a low-pressure distribution system. As a safety precaution, utility companies add an odorant to the gas (so we can smell it in case of a leak) and then send it to us through a network of smaller pipelines.

To complete the long journey, the natural gas must go through a device called a regulator to decrease the pressure even further so it is safe to enter our homes. The gas travels through our meters to measure the amount of gas we consume. Now that it has finished its incredible journey of being extracted, gathered, processed, transported, and distributed, the natural gas is finally ready to be put to good use (Go Natural Gas Inc., 2009).

According to US DOE, (2013), some of the advantages of Natural Gas are that: it produces roughly 20% to 45% less smog pollutants than other fuels; it emits about 5% to 9% less greenhouse gas than other fuels; it is also cheap compared to other fuels like gasoline.

Its main disadvantages are that it has limited vehicle availability and it is less readily available than gasoline and diesel.

2.2 WHAT CNG ACTUALLY IS

Compressed natural gas, or CNG, is natural gas under pressure which remains clear, odorless, and non-corrosive. Although vehicles can use natural gas as either a liquid or a gas, most vehicles use the gaseous form compressed to pressures above 3,100 pounds per square inch (CEC, 2013).

According to Wikimedia Foundation Inc., (2013), compressed natural gas (CNG) is a fossil fuel substitute for gasoline (petrol), Diesel fuel, and propane/LPG. Although CNG's combustion does produce greenhouse gases, it is widely considered a more environmentally "clean" alternative to conventional fuels; plus, it is much safer than other fuels in the event of a spill (as natural gas is lighter than air, and disperses quickly when released). CNG may also be mixed with biogas (produced from landfills or wastewater).

CNG is made by compressing natural gas (which is mainly composed of methane, CH_4), to less than 1% of the volume it occupies at standard atmospheric pressure. It is stored and distributed in hard containers at a pressure of 200–248 bar (2,900–3,600 psi), usually in cylindrical or spherical shapes.

CNG is used in traditional gasoline/internal combustion engine automobiles that have been converted into bi-fuel vehicles (gasoline/CNG). According to Mumtaz, (2011), natural gas vehicles are increasingly used in Iran, the Asia-Pacific region (especially Pakistan and the Indian capital of Delhi, and other large cities like Ahmedabad, Mumbai, Kolkata, Chennai, etc), Latin America, Europe, and North America due to rising gasoline prices (International Association for Natural Gas Vehicles, 2010). In response to high fuel prices and environmental concerns, CNG is starting to be used also in tuk-tuks and pickup trucks, transit and school buses, and trains.

The cost of conversion is a barrier to wider/quicker adoption of CNG as a fuel. It is also why municipal government, public transportation vehicles were the most visible early adopters of it, as they can more quickly amortize the money invested in the new (and usually cheaper) fuel. In spite of these circumstances, the number of vehicles in the world using CNG has grown steadily (30% per year (Consulate of the Argentinian Republic, 2009).

CNG's volumetric energy density is estimated to be 42% that of liquefied natural gas (because it is not liquefied), and 25% that of Diesel fuel (Wikimedia Foundation Inc., 2013).

In smaller fueling locations and on vehicles, CNG is stored in thick-walled steel, aluminum, or composite tanks built to last more than 20 years.

When released, compressed natural gas will mix with air and become flammable only when the mixture is within 5 to 15 percent natural gas. When the mixture is less than 5 percent natural gas, it doesn't burn. When the mixture is more than 15 percent natural gas, there is not enough oxygen to allow it to burn. Because natural gas is lighter than air, it quickly dissipates when released from tanks (CEC, 2013).

Go Natural Gas Inc., (2009), in their work wrote that natural gas vehicles are safer than diesel or gasoline propelled vehicles due to three main factors:

- The physical properties of natural gas;
- The integrity of the natural gas tank which is designed on more stringent safety standards;
- The fuel delivery method.

Natural gas has a very limited range of flammability and does not burn between concentrations of 5% and 15% when mixed with air. Gasoline and diesel burn at lower concentrations and ignite at lower temperatures.

Natural gas is non-toxic and does not have potential to contaminate groundwater if there is a fuel release. Natural gas is lighter than air. If a leak were to occur, the gas would dissipate to the atmosphere with little possibility of ignition. Gasoline and diesel pool on the ground in a liquid state and is easily ignitable.

The CNG tank in a vehicle is much more secure than a conventional gasoline tank. Gasoline tanks are normally composed of plastic, which is less secure than a strong natural gas cylinder of pure steel. Also, once the pressure of the line from the gas cylinder to the engine exceeds a certain amount, the gas cylinder's valve will automatically shut.

The transportation of natural gas from a gas well to the CNG dispenser requires a network of interconnected, underground pipelines which have already been installed and are convenient to tap into. This is the safest way to transport energy to the consumer. The transportation of gasoline and diesel require large tanker trucks on the road which have to possibility of spilling or getting into an accident.

Gasoline and diesel must be processed from crude oil in a large, complex oil refinery. Natural gas requires very little processing to make it suitable for use as a fuel.

Compressed Natural Gas (CNG) is significantly lower in price per gallon compared to gasoline and diesel.

Natural Gas is mainly produced from domestic sources (North America). It is estimated that the United States can supply natural gas for approximately 118 years.

CNG is significantly lower in emissions of greenhouse gases, smog, and particulates when compared to conventional petroleum fuels such as gasoline and diesel.

2.3 USING NATURAL GAS IN TRANSPORTATION

Nigeria's transportation system has in the last decade been incessantly beleaguered with problems. These problems arose mainly due to over dependence on petroleum products hence resulting to acute shortage of these products. It has had a telling effect on the nation and has forced the government and multinational companies to redress the issue of petrol and diesel usage as fuel. Alternative means was sought for and the most appropriate candidate was natural gas because of its versatility.

It is locally available at an affordable price. It is safer and more environmental friendly compared to petrol/diesel. This development now necessitated an in-depth study in the characteristic of natural gas and its economic viability as fuel. Various individuals and groups under-took this study and their work has been carefully recorded and presented below:

Okoro, (1993), Adeyemi and Ikoku, (1991) suggested an alternative fuel for the country's transportation system other than solely relying on gasoline/diesel engine vehicles only. This is to reduce our dependence on gasoline and diesel consumed locally and diversifies our transportation fuel. This move will lead to saving of gasoline for export and make diesel available for industrial use. If the alternative fuel utilization is encouraged, the social problem that may arise from subsidy removal to curb smuggling of petroleum product will be minimized.

Agbah, (1992), identified the need of gas as a fuel sources because of the effect of oil fuel exhaust production on the environment. He stated using natural gas instead of gasoline or diesel fuel in motor vehicles reduces CO_2 emission by 30% approximately per mile.

Ughamadu, (1992), said the use of CNG will go a long way in helping Nigerians contribute to the recent call of the United Nation on the need to reduce carbon emission resulting from oil based fuels as it poses an environmental problem worldwide.

Isiwu, (1997), in a recent publication noted that Nigeria is losing 228 barrels in crude oil equivalent of natural gas through flaring. This is about N365 million daily due to gas flaring in the country, 80% of our associated gas produced during oil production, this study will go a long way to justify the need for converting diesel fuel vehicles in Nigeria.

According to Onyiuke (1993), in NAPETCOR, a quarterly magazine of NNPC (1993) Vol. 14 No 2, NNPC through its subsidiary the NGC embarked on the use of CNG as an alternative fuel for vehicle in 1989 as another way to promote and encourage private individual in the utilization of CNG in the country.

Natural gas is produced both worldwide and domestically at relatively low cost and is cleaner burning than gasoline or diesel fuel. Natural gas vehicles show an average reduction in ozone-forming emissions of 80 percent compared to gasoline vehicles.

CNG vehicles have been introduced in a wide variety of commercial applications, from light-duty trucks and sedans - like taxi cabs, to medium-duty trucks - like UPS delivery vans and postal vehicles, to heavy-duty vehicles like transit buses, street sweepers and school buses. In California, transit agency buses are some of the most visible CNG vehicles. Figs 2.1 and 2.2 below are some of the CNG-powered vehicles (CEC, 2013).

Fig 2.1: CNG-powered Heavy-duty Street Sweeper

Source: CEC, (2013)

Fig 2.2: A CNG powered high-floor Neoplan AN440A, operated by ABQ RIDE in Albuquerque, New Mexico.

Source: Wikimedia, (2013)

Natural gas vehicles (NGVs) operate on the same basic principles as gasoline-powered vehicles. The fuel is mixed with air and fed into the cylinder where it is then ignited by a spark plug to move a piston up and down. Natural gas can power all the same vehicles currently powered by PMS and AGO fuel – light-, medium and heavy-duty; on-road and off-road. However, since natural gas is a gas rather than a liquid at standard pressure and temperature, some modifications are required to make an NGV work efficiently. These changes are primarily in the fuel storage tank, fueling receptacle/nozzle and the engine (NGV America, 2013).

Some people as well argue whether cars should run on CNG. They are of the opinion that it's a lot easier if natural gas is turned into gasoline.

According to Helman, (2013), there may well be a place at the margin for cars and trucks that run on CNG and LNG, but right now the technology is little more than a gimmick for companies looking to burnish their green credentials. Last year automakers sold an estimated 20,000 natural gas-powered vehicles — that's less than 1% of annual unit sales on the order of 16 million. Price is a big problem. A CNG-powered Honda Civic costs about $8,000 more than a regular model. Considering the trillions of dollars already invested in gasoline powered cars and the coast-to-coast distribution network to keep them filled up, it might make more sense to integrate natural gas into the existing system rather than seek to create an all new one in parallel.

2.4 PRODUCTION OF CNG

According to Shode, (2012), compressed Natural Gas ("CNG") is made by compressing natural gas to less than 1% of the volume it occupies at standard atmospheric pressure. CNG can be stored in steel or composite containers at a pressure of 200–248 bar (2900–3600 psi), usually in cylindrical vessels for storage and transportation over short/medium distances (10km to 100km on average).

2.4.1 CNG Value Chain

CNG is produced from natural gas. The typical value chain of processes that underlie the conversion of pipeline natural gas to CNG is shown below:

1. Sourcing of natural gas from the pipeline - A new spur line is constructed to connect the CNG plant location to the existing gas pipeline via the shortest route.

2. Mother Station - Natural gas supply (post filtration and metering) is then fed into dryers to remove any form of moisture from it. The gas is thereafter fed to the compressor. The compressor serves mainly to increase the pressure from the pipeline pressure to the desired pressure for CNG, in this case from 7-19 barg to 200-300barg).

3. Transportation and Storage - After the compression, the compressed gas is ready for dispensing directly to the tube trailers for transfer to the customers. When no trailers are available to load, the compressed gas shall be stored in steel cylinders, arranged in crates. These crates can be

loaded directly on trailers subsequently these trailers are then attached to truck-heads and driven to customer locations.

4. Gas fired power plant - Upon arrival at the customer location, the CNG trailer will be attached to a pressure reduction and metering station where the pressure would be reduced before it is then fed to the Gas fired plant for power generation.

Fig 2.3: CNG value chain

Source: Shode, (2012).

Increasingly, natural gas vehicles are finding their place on the roads -- especially in municipal and commercial applications. To make natural gas a viable fuel for vehicles, however, it must be compressed. This allows more fuel to be stored per volume, among other things. There are many different methods used to compress gasses. When it comes to natural gas, the most common method is the "diaphragm compressor."

The compressor contains a series of chambers, each one equipped with a specially designed membrane. Gas is pumped into the first chamber, where the volume is constricted by the membrane. Once this chamber is full, it is emptied into the next, smaller, chamber and so on down the line until the natural gas has reached the desired pressure (DeFranza, 2013).

Once the process is finished, the gas must be kept at pressure in tanks, like that seen in Fig 2.4.

Fig 2.4: Tanks for Storing CNG at Pressure

Source: DeFranza, (2013)

According to Gazprom, (2013), gas is compressed in order to reduce its volume. But CNG as fuel is much more eco-friendly than oil. And it is supposed to gradually replace oil in Russia.

Like any kind of gas, natural gas can be pressurized using a compressor. Its volume is thereby becoming significantly smaller. Natural gas is traditionally compressed to a pressure from 200 to 250 bars, which gives a 200-250-fold volume contraction.

Fig 2.5: Schematic of the Inner Chamber of a Natural Gas Compressor

Source: Gazprom, (2013)

Gas is compressed (pressurized) for transmission via gas trunklines to maintain proper pressure inside the reservoir (reservoir pressure) during the injection within the bedrock. Besides, CNG production is an intermediate stage of LNG production.

2.4.2 Generating CNG from Biogas

CNG is also generated from biogas. It is generating far more revenue per cubic meter of biogas than steam or electricity generation. It is the ultimate in the valorization of biogas.

Biogas from waste water treatment plant digesters and landfill gas is the feedstock of choice for this conversion. AirScience has the technology and the experience to build Biogas to CNG plants with capacity from 200 scfm to 3,000 scfm (AirScience Technologies Inc., 2013). CNG production units for generating CNG from biogas and the step-by-step process are shown in Figs 2.6 and 2.7 respectively.

Fig 2.6: CNG Production Units

Source: AirScience Technologies Inc., (2013)

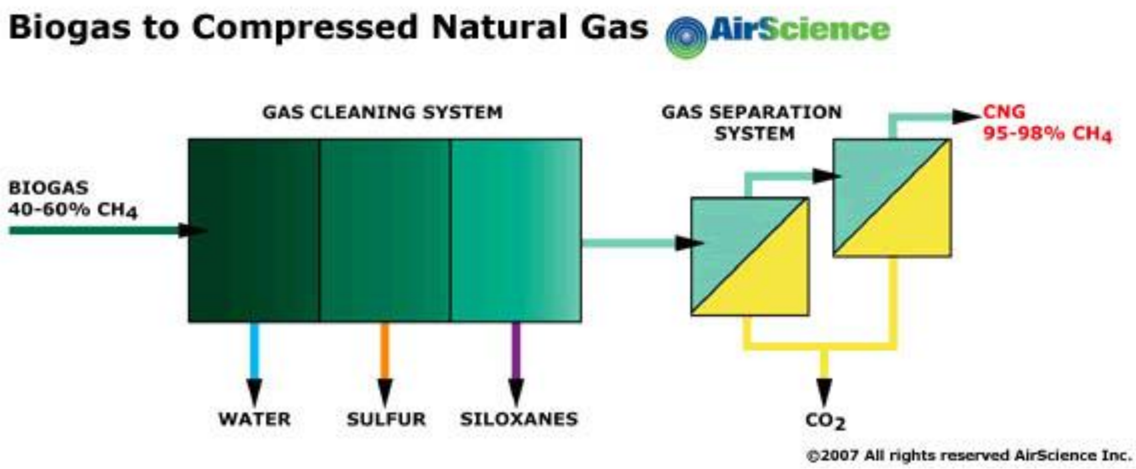


Fig 2.7: Schematic of the Process of Generating CNG from Biogas

Source: Air Science Technologies Inc., (2013)

2.5 MERITS AND DEMERITS OF CNG

2.5.1 Advantages of CNG

CNG does not contain any lead or benzene; so, the lead fouling of spark plugs is eliminated. CNG-powered vehicles have lower maintenance costs than other hydrocarbon-fuel-powered vehicles. CNG fuel systems are sealed, preventing fuel loses from spills or evaporation. Its use also ensures increased life of lubricating oils, as CNG does not contaminate and dilute the crankcase oil. Being a gaseous fuel, CNG mixes easily and evenly in air. CNG is less likely to ignite on hot surfaces, since it has a high auto-ignition temperature (540°C), and a narrow range (5–15%) of flammability (Gas Authority of India Limited, 2013).

Less pollution and more efficiency: CNG emits significantly less pollutants (e.g., carbon dioxide (CO_2), unburned hydrocarbons (UHC), carbon monoxide (CO), nitrogen oxides (NO_x), sulfur oxides (SO_x) and particulate matter (PM)) than petrol (California Air Resources Board, 2013).

It has a much higher octane number and lower cetane number which makes it a good fuel alternative for spark ignition engines.

A higher octane number makes it a superior fuel compared with petrol.

It has a very high octane number hence no anti knock additives are required.

Due to the absence of any lead or benzene content in CNG, the lead fouling of spark plugs and lead or benzene pollution is eliminated.

Being a gaseous fuel, CNG mixes with the air easily and evenly when dispersed

It is less likely to auto-ignite on hot surfaces when compared to gasoline or diesel and requires high compression energy for auto-ignition.

In case of a fuel spill, gasoline and diesel which are heavier that air, will collect and burn at ground level. Natural gas being lighter than air, in the case of leak, will burn above ground level and disperse into the atmosphere

Natural gas has a high ignition temperature of about 640 degrees Celsius, compared with a range of 230-280 degrees Celsius in the case of petrol.

It also has a narrow range of flammability i.e. natural gas will not burn with concentrations of below 5% and above 15% of air.

The high ignition temperature and limited flammability range of natural gas make accidental ignition or combustion unlikely.

The CNG kit is quite safe, and cylinders specially manufactured for use in vehicles are cast from a single piece of special steel alloy without any welded joints. Moreover, they are provided with 'burst discs' that rupture in case of inadvertent high pressure or fire, leaving no excessive pressure beyond the specified level, inside the cylinder.

CNG fittings and cylinder valve are enveloped inside a vapour bag with an outlet to the exterior. In case of a leak, the gas is released into the atmosphere harmlessly (Gaslink Nigeria Limited, 2006).

2.5.2 Disadvantages of CNG

Though CNG produces many advantages, it can't be denied that it also has its drawbacks. There are several disadvantages related to CNG such as the lack of fueling stations within regions. There are close to 120,000 natural gas vehicles in the United States and around 150,000 NGVs being used on the road; the most of them consisting of trucks. Altogether, there are about 10 million natural gas powered vehicles in the world. To cater for this need, it is estimated that there are only about 1,500 natural gas fueling stations on a national scale in the US. Only about half of these stations are made open to the public. In contrast, there are more than 190,000 gasoline stations in the US. Many vehicle owners are reluctant to switch to CNG as an alternative fuel because of the difficulty to refuel if they drive to locations that are not equipped with CNG stations. Car users find it more convenient to utilize petrol as their source of fuel as it is easily accessible everywhere. This short of fueling infrastructures has led many parties to turn down CNG as their main fuel for their vehicles. If the use of CNG increases, it is still questionable whether the infrastructure can be developed at a matching pace worldwide, considering the cost to be incurred.

Besides the fact that fuel stations are rather limited, vehicle owners have doubts about the usage of CNG for their vehicles. This is because CNG vehicles presently own a lesser range compared to gasoline powered vehicles. An energy gallon equivalent of natural gas, whether compressed natural gas or liquid natural gas, contains less energy, if measured up against a volumetric gallon of petrol or diesel fuel. It is said that compressed natural gas needs to be keep at extremely high pressure, close to 4,000 pounds per square inch, to attain satisfactory driving range. Attempts have been made by liquefied natural gas to rectify this problem but it requires special storage equipment on-board. This is very troublesome and will also bring about additional cost. Considering this, vehicles running on natural gas are not as good as their gasoline counterparts when it comes to travelling long distance. The lesser driving range offered by CNG powered vehicles once again cause consumers to have a better preference for cars using gasoline.

It must also be noted that vehicles operating on CNG cost more than vehicles running on gasoline. This is because natural gas vehicles have to be installed with additional components for the storage of fuel, which is more costly than gasoline tanks. For example, the Honda Civic Sedan that consumes gasoline costs around $22,255 in the United States. On the other hand, the Honda Civic GX, which is a natural gas consumer car, is priced at $24,590. While the cars running on petrol are much cheaper and can be purchased everywhere, natural gas vehicles are sold in selected places such as California and New York. Besides, gasoline fueled vehicles come in a variety of specifications which could travel a longer distance compared to natural gas vehicles. Consumers today have very high demands about their purchases and style of living, and they go for the best of both worlds in order to gain value for their money. Vehicle owners want to have choices when it comes to the type of car, design and suitability to meet their needs in addition to the ability to travel long distance, for a lower price tag. This is where gasoline consuming vehicles have the upper hand and CNG powered vehicles fail to provide.

In addition, gasoline powered vehicles could also be converted to CNG. The conversions of gasoline powered vehicles to use CNG are expensive and time consuming. Natural gas vehicles which have been specially manufactured in factories are designed in such a way to increase the efficiency of natural gas uses. Conversion is therefore a drawback because these vehicles are designed to take advantage of the higher octane of CNG which results in better engine competence. Many of the CNG powered vehicles today are vehicles that were originally gasoline powered. These vehicles have been modified to be bi-fueled, which allows both gasoline and natural gas consumption. Conversions are known for using its existing engine on the contrary to factory produced CNG vehicles. Although the conversions let vehicles users have more flexibility in choosing either gasoline or natural gas, the process of modification is costly and decreases efficiency.

Furthermore, the switching of gasoline powered vehicles to CNG would significantly add to the quantity of natural gas consumed in the region. The United States of America is currently very dependent upon natural gas for the use of electricity. If more vehicles owners convert their gasoline vehicles to compressed natural gas, or if more natural gas vehicles are produced, this will directly cause an upward trend in the consumption of CNG. This is where natural gas will be needed in high demand to supply both electricity as well as fuel for vehicles. The other alternative for electricity is wind power, but it is believed to be undependable as it needs to be backed up by conventional facilities. Natural gas is known to be the most general backing for wind turbines. As it is well known in the theory of economics, an increase in demand will cause a rise in price. If the demand for CNG increases and its supply is unable to follow suit at an equal or higher rate, this will translate into an increase in utility bills. Then, although CNG is currently cheaper than gasoline, the usage of CNG overall may actually become more expensive to the consumer.

Apart from that, CNG fuel tanks are very bulky, and they are said to be about half-inch thick aluminum covered with shatterproof fiberglass. CNG vehicles are much heavier and larger if they were to be compared to a conventional gasoline tank. They are also more cumbersome to install when measured up to Liquefied Petroleum Gas tanks which are immense. This is predominantly a disadvantage to smaller vehicles because a fuel tank in CNG vehicles takes up ample of space. For instance, a fuel tank in a CNG vehicle such as Nazaria could take up plenty of trunk space to a point where there is only enough space for two small suitcases. The same applies to a NGV model of the Honda Civic. Vehicle owners who have families will view this as a huge shortcoming, especially during times of travelling for longer distances in festive seasons, where trunk space for luggage and storage is essential. This disadvantage therefore causes inconvenience for CNG vehicles users.

Though CNG produces various weaknesses, it is still widely used on a national scale. It is still uncertain if there would be any considerable increase in the usage of natural gas to power more vehicles. Many parties involved have generally not been able to prove the efficiency of CNG which often resulted in unintentional consequences. Therefore, more research has to be done in terms to find a better and suitable alternative if CNG was to be replaced. However, considering the ever increasing price of gasoline and its benefits to the environment, compressed natural gas seems to be the alternative fuel for the future and is expected to be around (Gaslink Nigeria Limited, 2006).

Compressed natural gas vehicles require a greater amount of space for fuel storage than conventional gasoline powered vehicles. Since it is a compressed gas, rather than a liquid like gasoline, CNG takes up more space for each gasoline gallon equivalent (GGE). Therefore, the tanks used to store the CNG usually take up additional space in the trunk of a car or bed of a pickup truck which runs on CNG. This problem is solved in factory-built CNG vehicles that install the tanks under the body of the vehicle, leaving the trunk free (e.g., Fiat Multipla, New Fiat Panda, Volkswagen Touran Ecofuel, Volkswagen Caddy Ecofuel, Chevy Taxi -

which sold in countries such as Peru). Another option is installation on roof (typical on buses), requiring, however, solution of structural strength issues. CNG-powered vehicles are considered to be safer than gasoline-powered vehicles (Clean Vehicle Education Foundation, 2008).

2.6 STORAGE AND DISTRIBUTION OF CNG

Most NGVs operate using compressed natural gas (CNG) so the fuel takes up less space. CNG is stored on board vehicles in high-pressure (3,000-3,600 pounds per square inch) in tube-shaped cylinders that are attached to the rear, top or undercarriage of the vehicle. The cylinders meet very rigorous safety standards. They are made of high-strength materials designed to withstand impact, puncture and, in the case of fire, their pressure relief devices (PRDs) provide a controlled venting of the gas rather than letting the pressure build up in the tank.

Natural gas may also be stored on-board in the form of liquefied natural gas or LNG. To become LNG, natural gas must be cooled to –260 degrees Fahrenheit. The biggest advantage of LNG over CNG is space requirements. LNG requires only 30 percent of the space of CNG to store the same amount of energy. In order to keep the LNG cold, LNG is stored on-board vehicles in thermal storage tanks, in other words, sophisticated thermos bottles (NGV America, 2013).

Unlike gasoline or diesel stations, compressed natural gas stations are not "one size fits all." Building a CNG station for a retail application or a fleet requires calculating the right combination of pressure and storage needed for the types of vehicles being fueled. Making the right choices about the size of compressor and the amount of storage at the station makes a big difference in the cost of fuel and range for vehicles (US DOE, 2013).

City of Burbank's 24-hour CNG Fueling Station

Fig 2.8: CNG Fueling Station

Source: CEC, (2013)

Fig 2.9 shows a typical CNG meter used in CNG fuel stations.

Fig 2.9: CNG Meter used in Fueling Stations

Source: US DOE, (2013)

According to Gaslink Nigeria Limited, (2006), natural gas distribution is mainly through pipelines as this is the most cost effective solution.

CNG stations need to be connected to the pipeline to make CNG continuously available for dispensing.

Based on factors such as connectivity to pipeline, presence of compressors, size of compressors and the facility for filling cascades, the CNG stations can be broadly categorized into 4 different segments:

Mother Stations

Mother stations are connected to the pipeline and have high compression capacity. These stations supply CNG to both vehicles and daughter stations (through mobile cascades).

Typically they have the capability of filling all types of vehicles.

Daughter Stations

The “Daughter Stations” dispense CNG using mobile cascades.

These mobile cascades are replaced when pressure falls and the pressure depleted mobile cascade is then refilled at the “Mother Station”.

There is a reduction in storage pressure at daughter stations with each successive filling. Once the storage pressure drops, the refueling time increases, while the quantity of CNG dispensed to vehicle decreases (Gaslink Nigeria Limited, 2006).

Daughter Booster Stations

Installing a booster compressor can eliminate drawbacks of daughter stations. The mobile cascade can be connected to the dispensing system through a booster. Daughter boosters (compressor) are designed to take variable suction pressure and discharge at constant pressure of 200 bars to the vehicle being filled with CNG (Gaslink Nigeria Limited, 2006).

Online Stations

CNG vehicle storage cylinders need to be filled at a pressure of 200 bar. “On-line Stations” are equipped with a compressor, which compresses low-pressure pipeline-gas to the pressure of 250 bar for dispensing CNG to the vehicle cylinder (Gaslink Nigeria Limited, 2006).

2.7 USES OF CNG

Worldwide, there were 14.8 million natural gas vehicles by 2011, led by Iran with 2.86 million, Pakistan (2.85 million), Argentina (2.07 million), Brazil (1.7 million), and India (1.1 million) (NGVC, 2013) with the Asia-Pacific region leading with 5.7 million NGVs, followed by Latin America with almost 4 million vehicles (International Association for Natural Gas Vehicles, 2010).

Several manufacturers (Fiat, Opel (General Motors), Peugeot, Volkswagen, Toyota, Honda and others) sell bi-fuel cars. In 2006, Fiat introduced the Siena Tetrafuel in the Brazilian market, equipped with a 1.4L fire engine that runs on E100, E25 (Standard Brazilian Gasoline), Gasoline and CNG.

Any existing gasoline vehicle can be converted to a bi-fuel (gasoline/CNG) vehicle. Authorized shops can do the retrofitting; this involves installing a CNG cylinder in the trunk, installing the plumbing, installing a CNG injection system and the electronics.

CNG locomotives are operated by several railroads. The Napa Valley Wine Train successfully retrofitted a diesel locomotive to run on compressed natural gas before 2002 (Doyle, 2002). This converted locomotive was upgraded to utilize a computer controlled fuel injection system in May 2008, and is now the Napa Valley Wine Train's primary locomotive (Winetrain, 2008). Ferrocarril Central Andino in Peru, has run a CNG Locomotive on a freight line since 2005 (Alvarado, 2005) CNG locomotives are usually diesel locomotives that have been converted to use compressed natural gas generators instead of diesel generators to generate the electricity that drives the motors of the train. Some CNG locomotives are able to fire their cylinders only when there is a demand for power, which, theoretically, gives them higher fuel efficiency than conventional diesel engines. CNG is also cheaper than petrol or diesel.

We require energy on a constant basis to heat our water, cook our food, warm our homes, and generate our electricity. Natural gas is one of the least expensive forms of energy available to residential and commercial consumers. The most common use for natural gas around homes is for hot water tanks and furnaces. Schools, office buildings, hotels, restaurants and many other commercial enterprises use natural gas for heating, cooling, and cooking.

About 75% of the natural gas consumed is used by the industrial sector (including electricity generation). It has numerous uses in the petroleum refining, metal, chemical, and plastic, food processing, glass and paper industries. The ingredients for plastic, anti-freeze, fertilizer, and fabric products are formed through the use of natural gas by-products such as ethane, propane, butane, and sulphur. The fact that natural gas is one of the cleanest, cheapest, and most cost-efficient sources of energy makes it easy to see why it is so commonly used. Alberta continues to be the Canadian leader in an extremely successful and expanding energy sector. About 80% of Canadian natural gas production comes from Alberta.

Presently in Nigeria, exploration of the opportunities presented by Compressed Natural Gas (CNG) is being championed by the Nigeria Gas Company. They have built gas stations at their Egbin and Warri offices and converted some of their vehicles to run on gas (Gaslink Nigeria Limited, 2006).

Economides et al., (2012), in their work outlined the possibility of the usage of CNG for enhanced oil recovery. According to them, the time has come for a new era in petroleum production worldwide (particularly in the very promising but remote deepwater and/or pre-salt basins) and, as usual, a crucial component will play a pivotal role. Marine compressed natural gas (CNG) has been considered in the past, primarily as a means of transportation, but proved unattractive for long distances or large volumes when compared with liquefied natural gas (LNG). However, marine CNG still remains economically attractive over shorter voyages (up to ~4000 km) and medium volumes, and recent advances in containment systems are poised to provide marine CNG with the best opportunity yet to emerge as a major enabler of new and previously stranded hydrocarbons by becoming an important optimization tool to petroleum well performance.

Almost half of offshore natural gas (SEC-type reserves) is considered “stranded” because of the high cost to harness it in remote locations and the lack of a suitable market for the gas. Most such reserves do not contain enough gas to justify their own gas-transmission or LNG solution. Furthermore, inoperable gas affects oil production in many adverse ways, from the logistics of handling and facilities’ capacity to the cost of the treatment itself. Marine CNG used as a wellhead fluid shuttling service can generate significant monetary benefits for an operator attributable directly to the new technology and its innovative application. This technology could enable a higher number of fields to become viable by simply dehydrating the wellhead gas (where carbon dioxide or sulfur are present in relevant quantities) and enabling the centralization of gas treatment plants.

2.7.1 Benefits of Using CNG

In high GOR wells, an increase in gas production can affect oil production adversely. To accept the increased gas production and still fit within the design and operating envelope of the associated facilities, oil production may have to be reduced. The innovative use of marine CNG technology can complement existing production systems and enable higher oil production.

This ability to handle raw gas can be used to advantage at the bidding process. E&P companies primarily target oil discoveries. A raw gas management and transportation solution would enable increased gas production (irrespective of sulfur or CO_2 composition) and be a welcome addition to the value of the upstream asset instead of a complex headache. The creative use of marine CNG in raw gas management and as a production tool becomes a value-enhancing activity in its own right.

Other benefits include:

- The relative ease of handling and construction of loading and offloading facilities allows reduced development time and provides flexibility in adjusting the system to changing production profiles.

- The floating nature of the production and transportation assets makes it easy to redeploy them to other locations when production volumes begin to decrease.

- Accelerated monetization of natural gas during the interim period of construction of LNG production facilities or long-distance gas transmission pipeline systems.

- Because the new-generation containment systems can handle raw gas directly from the wellhead, significant savings can be achieved by avoiding duplication of processing facilities when producing from remote fields and centralizing such facilities on large offshore platforms or on-shore.

- In case of failure, hybrid metal/composite and all-composite structures may allow leakage but will not collapse or burst, therefore avoiding gas containment explosion.

- New-generation gas containment systems are light, have higher specific properties and can weigh as much as 20 percent less than metal-based containment systems, thereby increasing transportation capacity and energy density and lowering the unit cost of transported gas.

Shuttling of raw gas is the only process to have a positive economic effect on overall production. Gas flaring and treated gas reinjection are techniques that enable sustainable oil production but at a loss of profit due to the high cost of the solution. The alternative to gas flaring is lower oil production and, in worst-case scenarios, shut-in production. With this new technology it is possible to deploy solutions in shorter time frames to complement existing production systems or form part of new production systems.

2.7.2 Potential Applications of CNG

- Enabling Higher Oil Production – Consider an offshore oil production facility with a maximum production capacity of 200000 barrels/day with 1.5 Bcf/day (GOR 7500 scf/stb). After three years, and unexpectedly, the producing GOR increases to 10000scf/stb, enabling only 150000 barrels/day to be produced. The lack of gas-handling capacity effectively shuts in the equivalent of $1.8 billion/year in revenue. Shuttling the excess raw gas and associated liquids can increase production by 50,000 barrels/day with minimal difficulty. Benefits: $5 million/day.

- Putting a Gas-Rich Well on Production – A new well is drilled on an existing offshore platform. Although it can deliver 15,000 barrels per day, a high GOR (e.g 10,000scf/stb) may preclude its inclusion in production if the gas treatment facilities or the gas transmission systems are maxed out or near capacity. Benefits from wellhead-shuttling services: $1.5 million/day.

- Standardization of Production – In the future, production systems for natural gas would be standardized long before drilling, discovery, and well completions. Ordinarily, the discovery fluids would dictate the size and complexity of surface facilities such as separation processes, dehydration, and sweetening. The exact volume requirements and impurities to be treated are not known at this stage. The new technology enables the acceptance of raw gas in all cases irrespective of its composition, thereby simplifying the production and commercialization phases and saving time and money. It is not uncommon, for example, for scheduling delays, cost overruns and additional fluid-processing requirements to almost double the original budget estimate.

• Offshore Gas Gathering and Transmission System – Deepwater and pre-salt basin exploration and production are extremely capital-intensive projects. Marine CNG can provide production flexibility where gas transmission systems may be operating close to capacity and further expansion is very expensive. Marine CNG enables sustainable production (no routine flaring) from remote fields by creating a flexible and dynamic floating system where the raw gas is taken from the satellite fields to the nearest platform with gas-injection facilities or with access to gas transmission systems or taken directly to shore. It is also feasible to utilize such a “hub and spoke” configuration to connect satellite fields with an offshore floating LNG production system. This application is extremely attractive from an economic viewpoint as it enables a greater volume of oil to be produced and unlocks gas production in a technical and commercially viable manner while meeting all applicable safety and environmental requirements.

• Alternative to Submarine Sour Gas Transportation Systems – Sour gas production systems must be designed to operate with a significant safety margin to accommodate uncertainty on the gas specification over time. As such systems are costly to deploy and maintain, they are designed to handle “worst case scenarios” and be virtually maintenance-free. They normally require the use of exotic materials and expensive internal cladding and external coating. A marine CNG alternative can provide scalability and significant schedule and capital savings.

2.8 CNG COST AND OTHER FUELS

CNG pricing is the key for the success of a CNG expansion program worldwide.

It is generally the cheapest priced auto fuel available; its competitive pricing provides incentives of adequate returns to stakeholders (Gaslink Nigeria Limited, 2006).

Southern California Gas estimates CNG currently costs about 40 percent less than gasoline. As of July 2005, PG&E charges approximately $1.40

per therm, equivalent to about $1.78 per gasoline gallon, for CNG used as a motor fuel (CEC, 2013).

Compressed Natural Gas is often confused with liquefied natural gas (LNG). While both are stored forms of natural gas, the key difference is that CNG is gas that is stored (as a gas) at high pressure, while LNG is stored at very low temperature, becoming liquid in the process. CNG has a lower cost of production and storage compared to LNG as it does not require an expensive cooling process and cryogenic tanks. CNG requires a much larger volume to store the same mass of gasoline or petrol and the use of very high pressures (3000 to 4000 psi, or 205 to 275 bar). As a consequence of this, LNG is often used for transporting natural gas over large distances, in ships, trains or pipelines, and the gas is then converted into CNG before distribution to the end user.

CNG can also be confused with LPG, which is liquefied propane. Unlike natural gas (mostly methane), propane can be compressed to a liquid without continual refrigeration. LPG is commonly used to fuel vehicles in Australia.

CNG can be stored at lower pressure in a form known as an ANG (Adsorbed Natural Gas) tank, at 35 bar (500 psi, the pressure of gas in natural gas pipelines) in various sponge like materials, such as activated carbon and metal-organic frameworks (MOFs). The fuel is stored at similar or greater energy density than CNG. This means that vehicles can be re-fuelled from the natural gas network without extra gas compression; the fuel tanks can be slimmed down and made of lighter, weaker materials (Shengqian M. et al, 2008).

Compressed natural gas is sometimes mixed with hydrogen (HCNG) which increases the H/C ratio of the fuel and gives it a flame speed about eight times higher than CNG (Wikimedia, 2013).

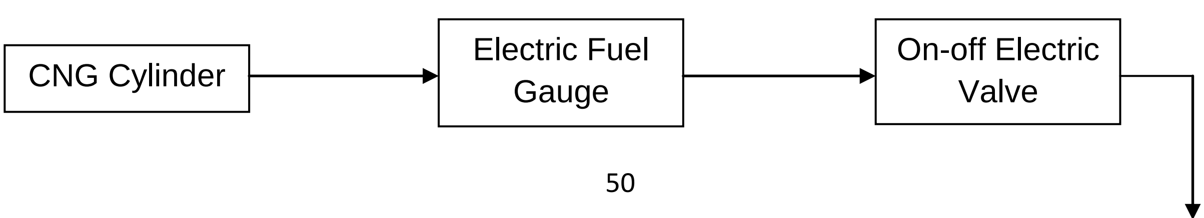
CHAPTER THREE

METHODOLOGY

3.1 CONVERTING AGO-POWERED VEHICLES TO CNG-POWERED VEHICLES

This conversion involves installing extra parts into the diesel-powered vehicles that would make them bi-fuel powered vehicles. This means that they would be able to be both powered by diesel and CNG.

The flow chart for the extra components and their connection sequence for the conversion of vehicles to CNG-powered are shown in Fig 3.1 below:



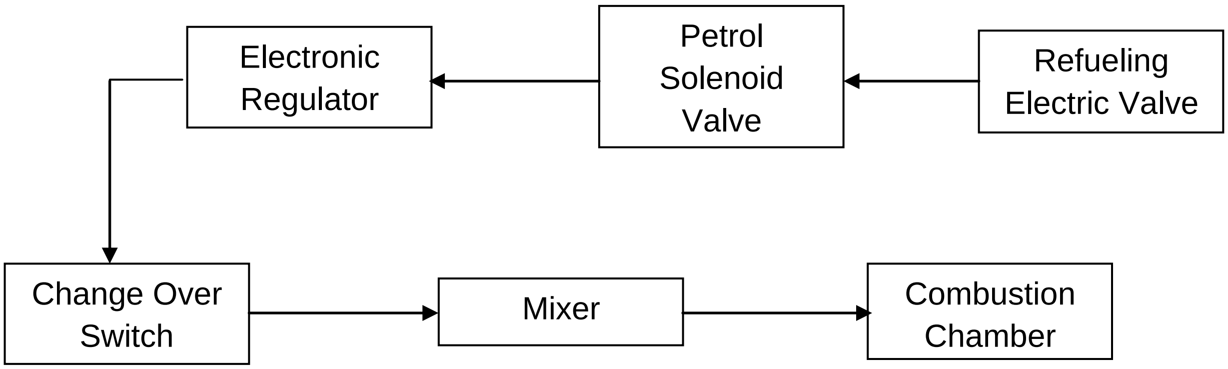


Fig 3.1: Flow Chart of the Installations for Converting Vehicles to CNG-powered

3.1.1 DESCRIPTION OF THE FLOW CHART

i. CNG Cylinder: The CNG cylinder is meant for storing CNG in the vehicle for use. CNG cylinders are manufactured from a special steel alloy and are seamless in construction. Their compact size allows them to easily fit into a small car.CNG cylinders are designed and built in such a way so as to withstand high pressure. The maximum pressure in a CNG cylinder is up to 200 bar.

ii. **Electric Fuel Gauge**: The electric fuel gauge is installed to check the level of CNG in the CNG cylinder and as such to show whether there is an enough fuel for an impending journey with the vehicle.

iii. **On-off Electric Valve**: The electric on-off control valve is a hydraulically operated sleeve type valve with an electric solenoid control. The flow through the valve is controlled by a rubber sleeve which is actuated by hydraulic pressure. The valve is either in the fully opened or the closed (shut off) position when operated electrically. When the selector is pointed to the “AUTO” position then the electric solenoid is used to automatically open or close the valve. The 3-way electric solenoid must be energized to open the valve and de-energized to close the valve. Pointing the manual selector handle to “OPEN” or “CLOSE” will override the “AUTO” control.

iv**. Re-fuelling Electric Valve**: This is a valve for dispensing natural gas. The valve itself functions as an internally piloted valve with a pilot orifice in the piston, which is one of the most important components of the valve. In order to withstand the high pressure, the piston is produced from a single piece of special plastic. Specially designed solenoid valves are required to control the flow of the CNG.

v**.CNG Solenoid Valve:** A solenoid valve is an electromechanically operated valve. The valve is controlled by an electric current through a solenoid: in the case of a two-port valve the flow is switched on or off; in the case of a three-port valve, the outflow is switched between the two outlet ports. Multiple solenoid valves can be placed together on a manifold.

Solenoid valves are the most frequently used control elements in fluidics. Their tasks are to shut off, release, dose, distribute or mix fluids. They are found in many application areas. Solenoids offer fast and safe switching, high reliability, long service life, good medium compatibility of the materials used, low control power and compact design.

vi.Electronic Regulator: Electronic fuel pressure regulator works directly with line of CNG pumps to reduce heat build-up and vapor lock conditions related to the operation.

vii. **Change Over Switch**: Change Over Switch is electronic control unit for interchange refinery fuel and gas of CNG injection cars. It is meant for switching from refinery fuel sucking to CNG sucking and vice versa.

viii**.Mixer:** This is a gas mixer for blending CNG and other additives required for its use in running vehicles. Conventional gas mixers have remained essentially unchanged for the past 40 years, based on proportional gas mix controlled manually and the need to increase the size of the mixer if a greater capacity is necessary. Furthermore, different gas mixtures often require different mixers to be used.

ix. **Combustion Chamber**: This is the unit where the CNG fuel burns to yield the amount of energy expended in the course of running the vehicle.

3.2 OUTPUT OF CNG-POWERED VEHICLES

3.2.1 Heating Values

The heating value of CNG is 1518533 KJ/scf and the heating value of diesel with density of 0.832 Kg/l is 37273.6 KJ/l (The Engineering Toolbox, 2013).

3.2.2 Gas Emissions

An engine running on petrol for 100 km emits 22,000 grams of CO_2, while covering the same distance on CNG emits only 16,275 grams of CO_2 (Natural Gas Supply Association, 2011). CNG is essentially methane, i.e., CH_4 with a calorific value of 900kJ/mol. This burns with oxygen to produce 1 mole of CO_2 and 2 moles of H_2O. By comparison, petrol can be regarded as essentially benzene or similar, C_6H_6 with a calorific value of about 3,300 kJ/mol and this burns to produce 6 moles of CO_2 and 3 moles of H_2O. From this it can be seen that per mole of CO_2 produced, CNG releases over 1.6 times as much energy as that released from petrol (or for the same amount of energy, CNG produces nearly 40% less CO_2).

The corresponding figures are 78 and 25.8 grams respectively, for nitrogen oxides. Carbon monoxide emissions are reduced even further. Due to lower carbon dioxide and nitrogen oxides emissions, switching to CNG can help mitigate greenhouse gas emissions (Gas Authority India Limited, 2013). The ability of CNG to reduce greenhouse gas emissions over the entire fuel lifecycle will depend on the source of the natural gas and the fuel it is replacing. The lifecycle greenhouse gas emissions for CNG compressed from California's pipeline natural gas is given a value of 67.70 grams of CO_2-equivalent per megajoule (gCO_2e/MJ) by the California Air Resources Board (CARB), approximately 28% lower than the average gasoline fuel in that market (95.86 gCO_2e/MJ). CNG produced from landfill biogas was found by CARB to have the lowest greenhouse gas emissions of any fuel analyzed, with a value of 11.26 gCO_2e/MJ (over 88% lower than conventional gasoline) in the low-carbon fuel standard that went into effect on January 12, 2010 (California Air Resources Board, 2013).

3.3 SAFETY OF CNG-POWERED VEHICLES IN COMPARISON TO AGO- VEHICLES

3.3.1 Detonability Limit (Volume% in air)

The detonability limit of CNG has been found to be 6.3% while that of diesel is 1.1%. This implies that more natural gas is required in air than diesel vapour in other to detonate it in the presence of any naked flame or spark.

3.3.2 Density Relative to Air

CNG at normal temperature is considerably less dense (0.128 kg/l) than air and when released from its tank it will rise, diffuse and disperse into the atmosphere. Diesel vapour is heavier than CNG at 0.832 kg/l and therefore takes longer to diffuse and disperse into the atmosphere, which makes diesel more dangerous than natural gas.

3.3.3 Flammability Limit (Volume% in air)

The flammability limit of CNG is 5% while that of diesel is 1%. This means that more natural gas must mix with air before the mixture can become combustible than is the case with diesel.

3.3.4 Auto-ignition Temperature

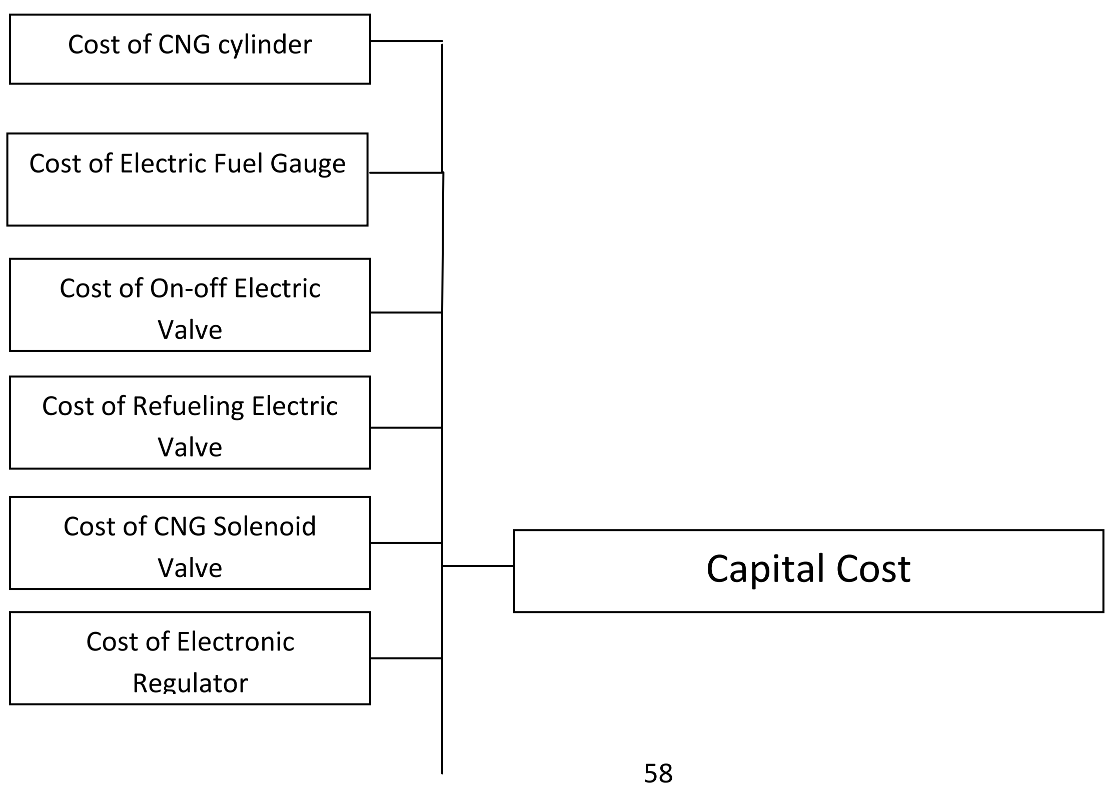
The temperature at which the CNG can become auto-ignited is much higher than that of diesel. This temperature for CNG is 540^0C and 228^0C to about 471^0C for diesel.

3.3.5 Diffusion Coefficient in Air

The rate at which CNG will diffuse into the air is faster than that of diesel. This diffusion rate is 0.16 meters per second for CNG and 0.05 for diesel. This significance of this is that it is more difficult for CNG to remain in the atmosphere than diesel. Thus, fire hazard persists longer with diesel. The above point buttresses the fact that CNG is safer than diesel as fuel.

3.4 EVALUATION OF THE ECONOMIC VIABILITY OF USING CNG-POWERED VEHICLES

The economic flow chart for running vehicles with CNG consists of the various costs at different stages: costs of putting the extra parts of the CNG-powered vehicle together, which are summed up to get the total capital cost as shown in Fig 3.2 below.


Cost of CNG cylinder
Cost of Electric Fuel Gauge
Cost of On-off Electric Valve
Cost of Refueling Electric Valve
Cost of CNG Solenoid Valve
Cost of Electronic Regulator
Capital Cost

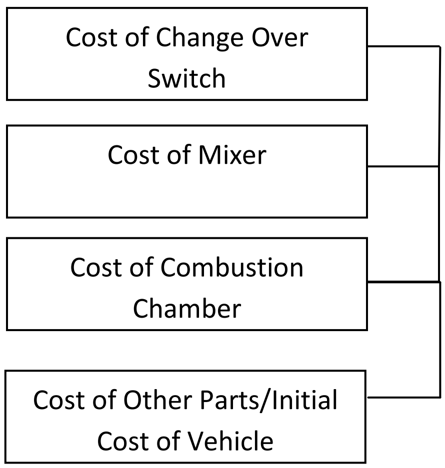


Fig 3.2: Economic flow chart for manufacturing CNG-powered vehicles

Costs Analysis

As with all infrastructural investments in the energy sector, manufacturing CNG-powered vehicles is capital intensive. Investors usually use the return on investment as a financial measure for the viability of such projects. It has been estimated that investors require a rate of return of 12% to 15% for regulated projects, and close to 20% for unregulated projects. The higher expected return from unregulated projects is due to the higher perceived market risk. In addition significant expenses are accumulated during the planning and location of potential storage sites to determine its suitability, which further increases the risk (American Gas Association, 1997).

The capital expenditure to manufacture the vehicle in Nigeria depends on the separate costs of the extra parts required to make the diesel-powered vehicles bi-fuel-powered vehicles.

The conversion rate from naira to dollar as at May 22, 2015 is given as:

$1 = N 180 3.1

Several items contribute to the total investment necessary to put CNG-powered vehicle into operation, as demonstrated in Fig 3.2. They include:

i. Cost of CNG Cylinder: The CNG cylinder is meant for storing CNG in the vehicle for use. CNG cylinders are manufactured from a special steel alloy and are seamless in construction. Their compact size allows them to easily fit into a small car. An empty CNG cylinder with a 50 liter-water-carrying capacity weighs 48 kg (approximately), and has a length of 835 mm and a diameter of 316 mm. The 50 liter capacity cylinder is the one most regularly used in CNG kits but cylinders with 45 liter, 55 liter, 60 liter and 65 liter capacity are used as well.

A cylinder with a 50 liter water-carrying capacity is capable of carrying approximately 9 kg of CNG. This is equivalent to 12.5 liters of petrol and will allow a run of about 150-160 km for a medium sized 1300 CC car. An electronic fuel gauge fitted on the dashboard which is part of the conversion kit indicates the quantity of CNG left in the cylinder.

CNG cylinders are designed and built in such a way so as to withstand high pressure. The maximum pressure in a CNG cylinder is up to 200 bar. CNG cylinders are safe as they are manufactured as per specific requirements and tested before use, in accordance with international specifications and standards, and are duly approved by the Chief Controller of Explosives (CCoE). Moreover, they are provided with a pressure relief device (PRD) that consists of a fusible plug and a burst disc that ruptures in case of extremely high pressure and temperature.

On an average, vehicle owners lose about one third of their boot space when a car is converted to CNG. The boot space also depends upon the size of vehicle and cylinder make. However people who wish to convert to CNG can still install carriers on their vehicles to compensate for the lost boot space (Mahanagar Gas Limited, 2013).

ii. Cost of Electric Fuel Gauge: The electric fuel gauge is installed to check the level of CNG in the CNG cylinder and as such to show whether there is an enough fuel for an impending journey with the vehicle.

iii. Cost of On-off Electric Valve: The electric on-off control valve is a hydraulically operated sleeve type valve with an electric solenoid control. The flow through the valve is controlled by a rubber sleeve which is actuated by hydraulic pressure. The valve is either in the fully opened or the closed (shut off) position when operated electrically. When the selector is pointed to the “AUTO” position then the electric solenoid is used to automatically open or close the valve. The 3-way electric solenoid must be energized to open the valve and de-energized to close the valve. Pointing the manual selector handle to “OPEN” or “CLOSE” will override the “AUTO” control. The manual selector can be used to hold the valve partly open by opening the valve part way and then pointing the selector handle midway between “OPEN” and “CLOSE” (Nelson Irrigation, 2013).

iv. Cost of Re-fuelling Electric Valve: This is a valve for dispensing natural gas. The valve itself functions as an internally piloted valve with a pilot orifice in the piston, which is one of the most important components of the valve. In order to withstand the high pressure, the piston is produced from a single piece of special plastic. Specially designed solenoid valves are required to control the flow of the CNG.

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vii. Cost of Change Over Switch: Change Over Switch is electronic control unit for interchange refinery fuel and gas of CNG injection cars. It is meant for switching from refinery fuel sucking to CNG sucking and vice versa.

viii. Cost of Mixer: This is a gas mixer for blending CNG and other additives required for its use in running vehicles. Conventional gas mixers have remained essentially unchanged for the past 40 years, based on proportional gas mix controlled manually and the need to increase the size of the mixer if a greater capacity is necessary. Furthermore, different gas mixtures often require different mixers to be used.

ix. Cost of Combustion Chamber: This is the unit where the CNG fuel burns to yield the amount of energy expended in the course of running the vehicle.

x. Cost of Other Parts: This is the cost of putting other parts and the required body parts of the vehicle in place. This may also be referred to as the initial cost of the diesel-powered vehicle before it is converted to a bi-fuel-powered vehicle.

The total capital cost is given as the sum of the costs i to x.

Annual Operating cost = Fuel cost + Maintenance cost 3.2

Gross Revenue = Driver's pay per km moved * Km covered by the vehicle running on the available volume of CNG 3.3

Net revenue for subsequent years of operation =

= Gross revenue – Annual Operating cost 3.4

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 RESULT

The values of the heating values and prices of CNG and diesel are as shown in Table 4.1 below:

Table 4.1: Heating Values and Prices of CNG and Diesel

CNG Heating Value	1518533 KJ/scf
Diesel Heating Value	37273.6 KJ/l
CNG Price	$0.38/l
Diesel Price	$0.50/l

Source: The Engineering Toolbox, (2013)

4.1.1 Costs Analyses for CNG-powered Vehicle

4.1.1.1 Total Capital Cost, (C)

4.1.1.1.1 Initial Cost of Vehicle, (I)

The cost of procuring a diesel-powered vehicle is $20000 = N3.6million

4.1.1.1.2 Cost of Installing the CNG Cylinder, (C_{CNG})

The cost of installing the CNG cylinder and its accessories is $280 = N50400

4.1.1.1.3 Cost of Electric Fuel Gauge, (EFG)

The installation of electric fuel gauge is set at $59.38 = N10688

4.1.1.1.4 Cost of On-off Electric Valve, (OEV)

The cost of buying and installing the on-off electric valve is $1000 = N180000

4.1.1.1.5 Cost of the Re-fuelling Electric Valve, (RE)

The cost of installing the re-fuelling valve is $800 = N144000

4.1.1.1.6 Cost of CNG Solenoid Valve, (SV_{CNG})

The installation of the CNG solenoid valve is set at $500 = N90000

4.1.1.1.7 Cost of the Electronic Regulator, (ER)

The cost of buying and installing electronic regulator is $100 = N18000

4.1.1.1.8 Cost of Installing Fuel Change Over Switch, (COS_{CNG})

The cost of installing the fuel change over switch is $200 = N36000

4.1.1.1.9 Cost of Installing Fuel Mixer, (M_{CNG})

The installation of fuel mixer is set at $10 = N1800

4.1.1.1.10 Cost of Installing Combustion Chamber, (CC)

The cost of installing the combustion chamber and Valve is \$1000 = N180000

Total Capital Cost (C) = I + C_{CNG} + EFG + OEV + RE + SV_{CNG} + ER + COS_{CNG} + M_{CNG} + CC 4.1

Total Capital Cost (C) = \$23949.38 = N4.31 million

4.1.1.2 Annual Cost, (A)

4.1.1.2.1 Fuel Cost, (F_c)

According to Watt, (2000), the average kilometer per liter covered by a vehicle running on CNG is 1.66km/l. A vehicle that plies Onitsha to Owerri and back would be covering a distance of 186km. If 1l of CNG can cover a distance of 1.66km then to cover a distance of 186km the volume of CNG that would be required is 112l. Since the cost of CNG is \$0.38/l, then the cost of 112l of CNG is \$42.6. If the vehicle travels to Owerri from Onitsha and back 15 times in a month it means that the cost of CNG for the 15 trips in a month is \$638.7. Then the annual cost of fuel would be \$638.7 * 12 = \$7664 = N1.38 million

4.1.1.2.2 Maintenance Cost, (M_c)

The cost of maintaining the vehicle, servicing the engine and other parts and repairing the damaged parts would amount to about $40 per month which is $480 ie N86400 annually.

Annual Cost, A = F_c + M_c = $7664 + $480 = $8144 = N1.47 million

4.1.2 Revenue Analyses for CNG-powered Vehicles

If the remuneration the driver of the vehicle gets for one trip from Onitsha to Owerri and back is $133, then Gross Revenue = $133 * 15 * 12 = $24000.

Annual Net Revenue = $24000 – $8144 = $15856 = N2.85 million

4.1.3 NPV and IRR for the CNG-powered Vehicle Project

Net Present Value, (NPV) is a measure of profitability of any project. The net present value of a time series of cash flows, both incoming and outgoing, is the sum of the present values (PVs) of the individual cash flows.

NPV compares the value of 1 dollar today to its value in future, taking inflation and returns into consideration. If the NPV of a prospective project is positive, it is accepted. However, if NPV is negative, the project should be discouraged because cash flows will also be negative (Wikimedia, 2013)

The cash flows for the CNG-powered vehicle project over the space of 15 years is shown in Table 4.2 below

Table 4.2: Cash Flows for the CNG-powered Vehicle Project over the space of 15 years

Time (yr)	CAPEX ($)	OPEX ($)	GROSS REV ($)	NCR ($)	CUM NCR ($)	PV @ 5% ($)	PV @ 10% ($)
0	23949	0	0	(23949)	(23949)	(23949)	(23949)
1	0	8144	24000	15856	(7193)	15101	14415
2	0	8144	24000	15856	8663	14382	13104
3	0	8144	24000	15856	24519	13697	11913
4	0	8144	24000	15856	40375	13045	10830
5	0	8144	24000	15856	56231	12424	9845
6	0	8144	24000	15856	72087	11832	8950
7	0	8144	24000	15856	87943	11269	8137
8	0	8144	24000	15856	103799	10732	7397
9	0	8144	24000	15856	119655	10221	6724
10	0	8144	24000	15856	135511	9734	6113
11	0	8144	24000	15856	151367	9271	5557
12	0	8144	24000	15856	167223	8829	5052
13	0	8144	24000	15856	183079	8409	4593
14	0	8144	24000	15856	198935	8008	4175
15	0	8144	24000	15856	214791	7627	3796

The cash flows in millions of Naira for the CNG-powered vehicle project over the space of 15 years is shown in Table 4.3 below:

Table 4.3: Cash Flows in millions of Naira for the CNG-powered Vehicle Project over the space of 15 years

Time (yr)	CAPEX (NM)	OPEX (NM)	GROSS REV (NM)	NCR (NM)	CUM NCR (NM)	PV @ 5% (NM)	PV @ 10% (NM)
0	4.31	0.00	0.00	(4.31)	(4.31)	(4.31)	(4.31)
1	0.00	1.47	3.86	2.85	(1.16)	2.43	2.32
2	0.00	1.47	3.86	2.85	1.39	2.32	2.11
3	0.00	1.47	3.86	2.85	3.95	2.21	1.92
4	0.00	1.47	3.86	2.85	6.50	2.10	1.74
5	0.00	1.47	3.86	2.85	9.05	2.00	1.59
6	0.00	1.47	3.86	2.85	11.61	1.90	1.44
7	0.00	1.47	3.86	2.85	14.16	1.81	1.31
8	0.00	1.47	3.86	2.85	16.71	1.73	1.19
9	0.00	1.47	3.86	2.85	19.26	1.65	1.08
10	0.00	1.47	3.86	2.85	21.82	1.57	0.98
11	0.00	1.47	3.86	2.85	24.37	1.49	0.89
12	0.00	1.47	3.86	2.85	26.92	1.42	0.81
13	0.00	1.47	3.86	2.85	29.48	1.35	0.74
14	0.00	1.47	3.86	2.85	32.03	1.29	0.67
15	0.00	1.47	3.86	2.85	34.58	1.23	0.61

From Table 4.2, the Net Present Value at an expected rate of return/discount rate (the rate which the capital needed for the project could return if invested in an alternative venture) of 5% is the sum of the present values in that column for 5%. The sum of the PVs at 5% is $141531 = N25.48 million

The NPV at a discount rate of 10% = $97553 = N17.56 million

The project is worth investing on since the NPV in both cases is greater than zero.

The internal rate of return (IRR) on investment of a project is the rate of return that makes the net present value of all cash flows from a particular investment equal to zero. The higher the IRR of a project, the more desirable it is to undertake the project. Table 4.3 is another table generated from Table 4.2 and it shows the cash flows for the project over 2 years. The essence of Table 4.4 is for the generation of the IRR of the project which has to be computed using very short times of undertaking the project. For more accurate values and for taking extreme cases, little number of years, like 2 to 4 years, is used in generating the IRR rather than large number of years. Table 4.4 is shown below:

Table 4.4: Cash Flows for the CNG-powered Vehicle Project over the space of 2 years

Time (yr)	CAPEX ($)	OPEX	GROSS REV ($)	NCR	CUM NCR	PV @ 5% ($)	PV @ 10% ($)

		($)		($)	($)		
0	23949	0	0	(23949)	(23949)	(23949)	(23949)
1	0	8144	24000	15856	(7193)	15101	14415
2	0	8144	24000	15856	8663	14382	13104

Table 4.5 is a table of the net present values for the CNG-powered vehicle project at various discount rates, which was used in generating a plot of NPV against discount rate as shown in Fig 4.1 for the determination of the IRR which is 24%. The 24% is the discount rate at which the NPV equals zero.

Table 4.5: NPV at various Discount Rates

Discount Rate (%)	NPV ($)
5	6433.812
10	4469.678
15	2728.24
20	1175.444
25	(216.36)
30	(1469.83)
35	(2603.68)
40	(3633.49)

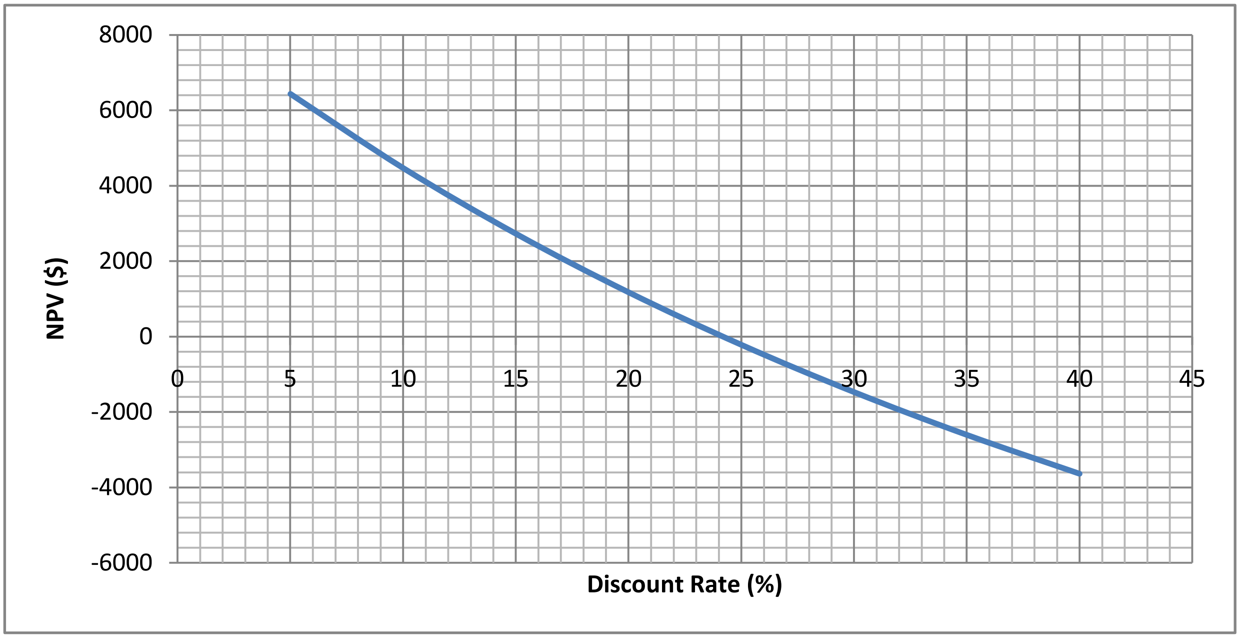

Fig 4.1: Plot of NPV against Discount Rate

4.1.4 Pay-out (PO) for the CNG-powered Vehicle Project

The pay-out for a project refers to the time (years) at which the initial investment on the project is just recovered. It is the time at which cumulative NCR becomes zero.

Table 4.6 shows the cumulative NCR and NCR after 7 years while Fig 4.2 represents the graph of time against cumulative NCR in billions of dollars for the CNG-powered vehicle project.

Table 4.6: Cum NCR after 7 years

Time (yr)	NCR ($)	CUM NCR ($)
0	(23949)	(23949)
1	15856	(7193)
2	15856	8663
3	15856	24519
4	15856	40375
5	15856	56231
6	15856	72087
7	15856	87943

From Fig 4.2, cumulative NCR becomes zero between the 1st and 2nd year. In this research work, 1 and 2 years were used as the initial point (IP) and final point, (FP) respectively.

Applying interpolation:

(PO – IP) / (FP – IP) = (0 – CUM NCR at IP) / (CUM NCR at FP – CUM NCR at IP) 4.2

(PO – 1yr) / (2yrs – 1yr) = (0 – (-7193)) / (8663 – (-7193))

PO = 1.45yrs as indicated in Fig. 4.2.

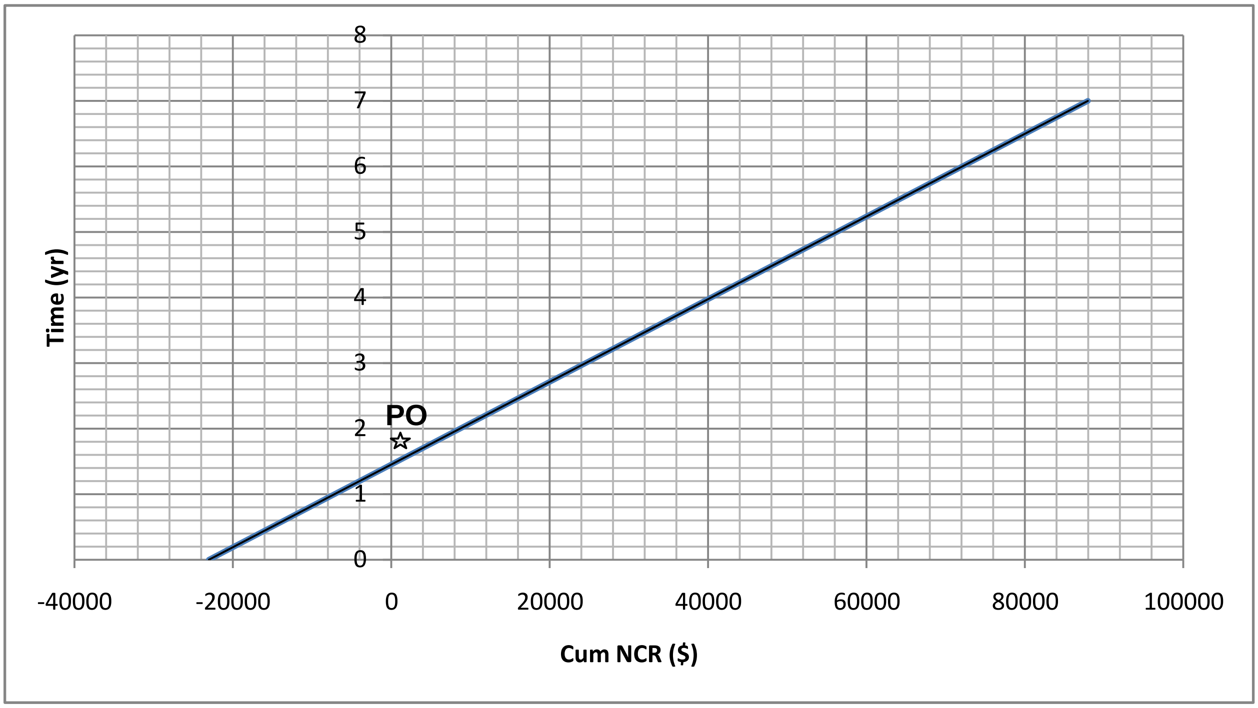

Fig 4.2: Plot of Time (yr) against Cum NCR ($)

4.1.5 Effect of CNG Price on the CNG-powered Vehicle Project

The NPV after 4 years at various CNG prices are as shown in Table 4.7 which was used to plot a chart of NPV ($) against CNG Price ($/l) as shown in Fig 4.3. From Fig 4.3, if CNG price goes higher than $1.18 per liter ie N212 per liter, then the NPV becomes negative and so it would not be advisable to invest in the CNG-powered vehicle project.

Table 4.7: Table of CNG Price ($/l) and NPV at 10% ($)

CNG Price ($/l)	NPV @ 10% ($)
0.38	66130.73
1.38	(17933.8)
2.38	(101998)
3.38	(186063)
4.38	(270127)

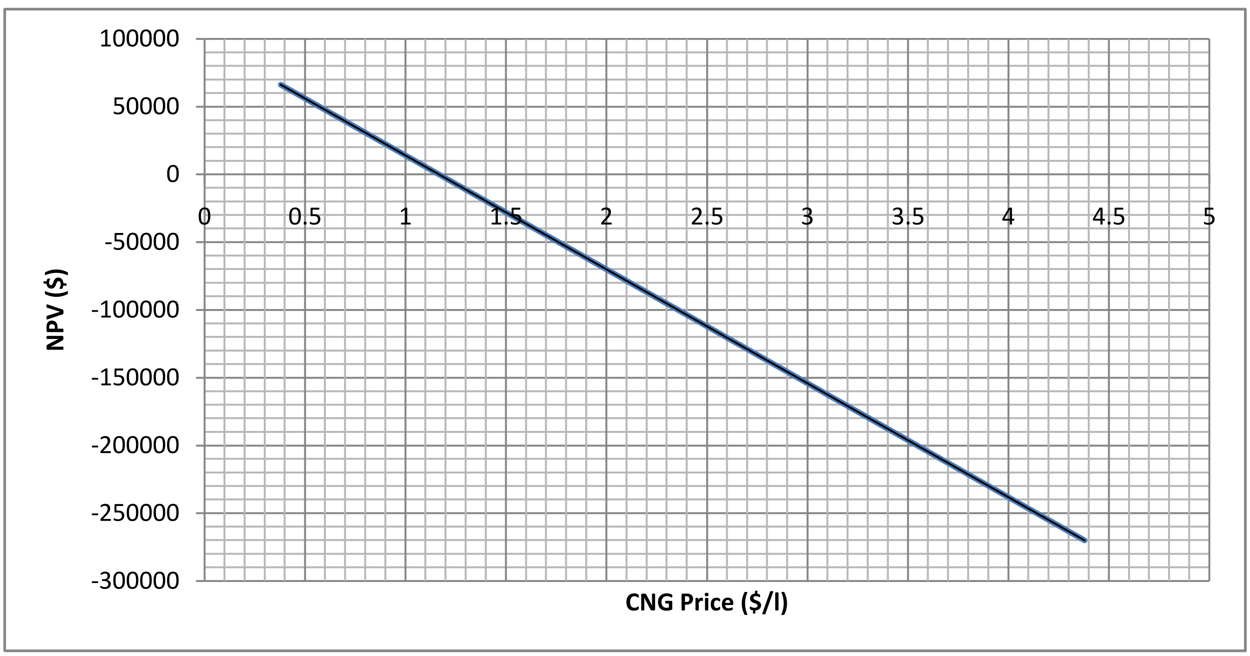

Fig 4.3: Plot of NPV ($) against CNG Price ($/l)

4.2 ECONOMIC ANALYSIS OF AGO-POWERED VEHICLE

4.2.1 Costs Analyses for AGO-powered Vehicle

4.2.1.1 Total Capital Cost, (C)

The Total Capital Cost = The Initial Cost of the AGO-powered Vehicle.

The cost of procuring a AGO-powered vehicle is $20000 = N3.60 million

4.2.1.2 Annual Cost, (A)

4.2.1.2.1 Fuel Cost, (F_c)

According to Watt, (2000), the average kilometer per liter covered by a vehicle running on diesel is 1.04km/l. A vehicle that plies Onitsha to Owerri and back would be covering a distance of 186km. If 1l of diesel can cover a distance of 1.04km then to cover a distance of 186km the volume of diesel that would be required is 178.8l. Since the cost of diesel is $0.5/l, then the cost of 178.8l of diesel is $89.4. If the vehicle travels to Owerri from Onitsha and back 15 times in a month it means that the cost of diesel for the 15 trips in a month is $1341. Then the annual cost of fuel would be $2550 * 12 = $16092 = N2.90 million

4.1.1.2.2 Maintenance Cost, (M_c)

The cost of maintaining the vehicle, servicing the engine and other parts and repairing the damaged parts would amount to about \$40 per month which is \$480 ie N86400 annually.

Annual Cost, $A = F_c + M_c$ = \$16092 + \$480 = \$16572 = N2.98 million

4.1.2 Revenue Analyses for Diesel-powered Vehicles

If the remuneration the driver of the vehicle gets for one trip from Onitsha to Owerri and back is \$133, then Gross Revenue = \$133 * 15 * 12 = \$24000.

Annual Net Revenue = \$24000 – \$16572 = \$7428 = N1.34 million.

4.1.3 NPV and IRR for the Diesel-powered Vehicle Project

The cash flows in millions of Naira for the diesel-powered vehicle project over the space of 15 years is shown in Table 4.8 below

Table 4.8: Cash Flows in millions of Naira for the Diesel-powered Vehicle Project over the space of 15 years

Time (yr)	CAPEX (NM)	OPEX (NM)	GROSS REV (NM)	NCR (NM)	CUM NCR (NM)	PV @ 5% (NM)	PV @ 10% (NM)
0	3.60	0.00	0.00	(3.60)	(3.60)	(3.60)	(3.60)
1	0.00	2.67	3.86	1.19	(2.03)	1.14	1.09
2	0.00	2.67	3.86	1.19	(0.83)	1.08	0.99
3	0.00	2.67	3.86	1.19	0.36	1.03	0.90
4	0.00	2.67	3.86	1.19	1.56	0.98	0.82
5	0.00	2.67	3.86	1.19	2.75	0.94	0.74
6	0.00	2.67	3.86	1.19	3.94	0.89	0.67
7	0.00	2.67	3.86	1.19	5.14	0.85	0.61
8	0.00	2.67	3.86	1.19	6.33	0.81	0.56
9	0.00	2.67	3.86	1.19	7.53	0.77	0.51
10	0.00	2.67	3.86	1.19	8.72	0.73	0.46
11	0.00	2.67	3.86	1.19	9.91	0.70	0.42
12	0.00	2.67	3.86	1.19	11.11	0.66	0.38
13	0.00	2.67	3.86	1.19	12.30	0.63	0.35
14	0.00	2.67	3.86	1.19	13.50	0.60	0.31
15	0.00	2.67	3.86	1.19	14.69	0.57	0.29

From Table 4.8, the Net Present Value at an expected rate of return/discount rate (the rate which the capital needed for the project could return if invested in an alternative venture) of 5% is the sum of the present values in that column for 5%. The sum of the PVs at 5% is N9.17 million

The NPV at a discount rate of 10% = N5.86 million

The project is worth investing on since the NPV in both cases is greater than zero.

The internal rate of return (IRR) on investment of a project is the rate of return that makes the net present value of all cash flows from a particular investment equal to zero. The higher the IRR of a project, the more desirable it is to undertake the project. Table 4.9 is another table generated from Table 4.8 and it shows the cash flows for the project over 4 years. The essence of Table 4.9 is for the generation of the IRR of the project which has to be computed using very short times of undertaking the project. For more accurate values and for taking extreme cases, little number of years, like 2 to 4 years, is used in generating the IRR rather than large number of years. Table 4.9 is shown below:

Table 4.9: Cash Flows in millions of Naira for the Diesel-powered Vehicle Project over the space of 4 years

Time (yr)	CAPEX (NM)	OPEX (NM)	GROSS REV (NM)	NCR (NM)	CUM NCR (NM)	PV @ 5% (NM)	PV @ 10% (NM)
0	3.66	0.00	0.00	(3.66)	(3.66)	(3.66)	(3.66)
1	0.00	2.67	3.86	1.19	(2.03)	1.14	1.09
2	0.00	2.67	3.86	1.19	(0.83)	1.08	0.99
3	0.00	2.67	3.86	1.19	0.36	1.03	0.90
4	0.00	2.67	3.86	1.19	1.56	0.98	0.82

Table 4.10 is a table of the net present values for the diesel-powered vehicle project at various discount rates, which was used in generating a plot of NPV against discount rate as shown in Fig 4.4 for the determination of the IRR which is 18%. The 18% is the discount rate at which the NPV equals zero.

Table 4.10: NPV at various Discount Rates

Discount Rate (%)	NPV (NM)
5	1.013865
10	0.564819
15	0.188844
20	(0.12905)
25	(0.40025)
30	(0.63351)
35	(0.83564)
40	(1.01202)

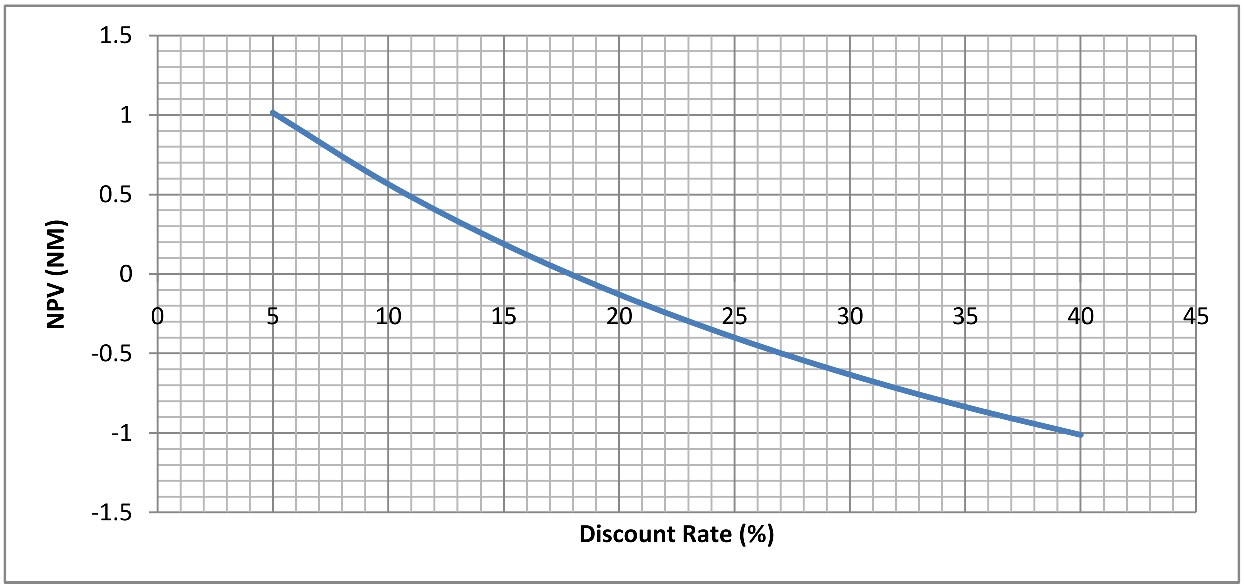

Fig 4.4: Plot of NPV against Discount Rate

4.1.4 Pay-out (PO) for the Diesel-powered Vehicle Project

The pay-out for a project refers to the time (years) at which the initial investment on the project is just recovered. It is the time at which cumulative NCR becomes zero.

Table 4.11 shows the cumulative NCR and NCR after 7 years while Fig 4.5 represents the graph of time against cumulative NCR in millions of Naira for the diesel-powered vehicle project.

Table 4.11: Cum NCR after 7 years

Time (yr)	NCR (NM)	CUM NCR (NM)
0	(3.66)	(3.66)
1	1.194	(2.026)
2	1.194	(0.832)
3	1.194	0.362
4	1.194	1.556
5	1.194	2.75
6	1.194	3.944
7	1.194	5.138

From Fig 4.5, cumulative NCR becomes zero between the 2nd and 3rd year. In this research work, 2 and 3 years were used as the initial point (IP) and final point, (FP) respectively.

Applying interpolation:

(PO – IP) / (FP – IP) = (0 – CUM NCR at IP) / (CUM NCR at FP – CUM NCR at IP)

(PO – 2yrs) / (3yrs – 2yrs) = (0 – (- 0.832)) / (0.362 – (- 0.832))

PO = 2.7yrs as indicated in Fig. 4.5.

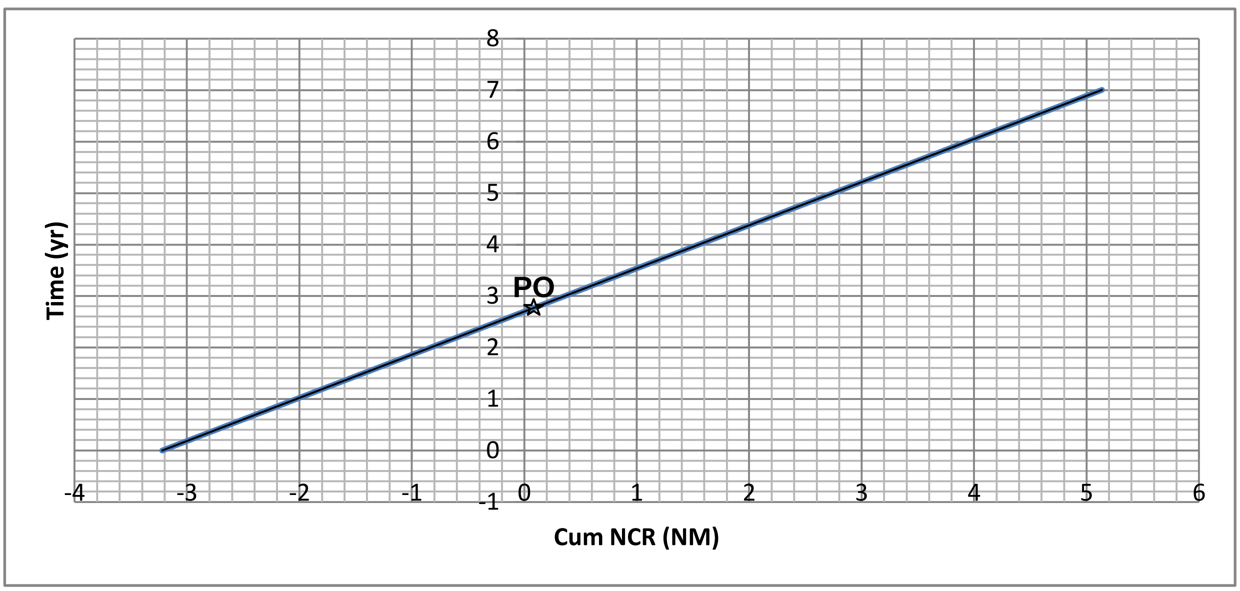

Fig 4.5: Plot of Time (yr) against Cum NCR (NM)

4.1.5 Effect of Diesel Price on the Diesel-powered Vehicle Project

The NPV at various diesel prices are as shown in Table 4.12 which was used to plot a chart of NPV (NM) against Diesel Price ($/l) as shown in Fig 4.6. From Fig 4.6, if diesel price goes below $0.7 per liter ie N126, then the NPV becomes negative and so it would not be advisable to invest in the diesel-powered vehicle project if you are to expect a rate of return of 10%.

Table 4.12: Table of Diesel Price ($/l) and NPV at 10% (NM)

Diesel Price ($/l)	NPV @ 10% (NM)
0.5	4.99
1.5	(16.62)
2.5	(38.23)
3.5	(59.83)
4.5	(81.44)
5.5	(103.05)

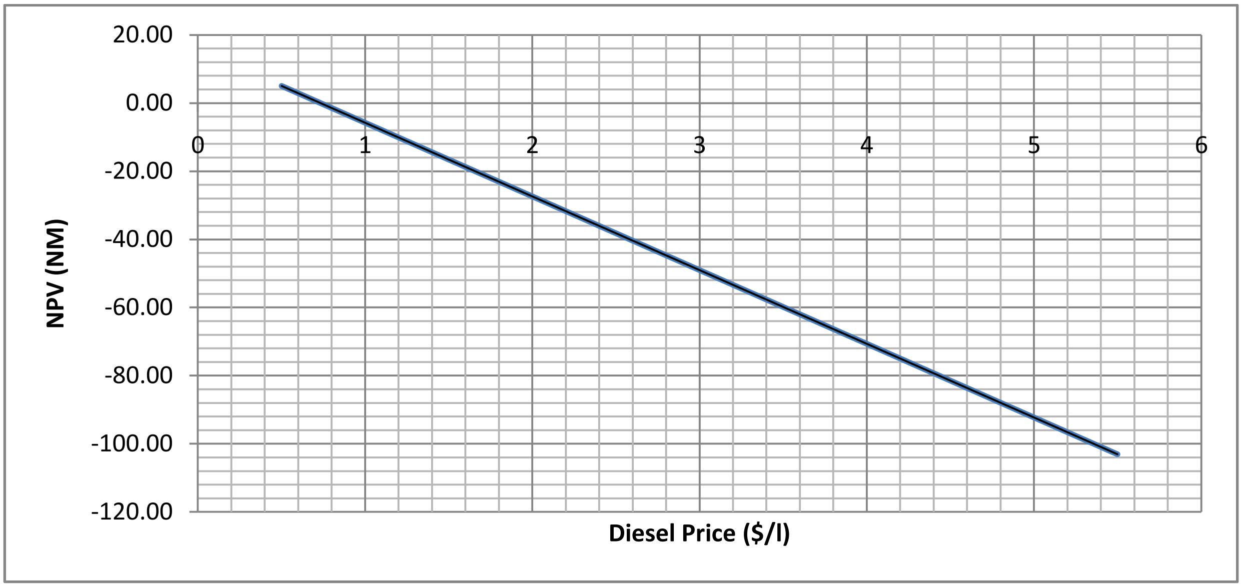

Fig 4.6: Plot of NPV ($B) against Diesel Price ($/l)

Table 4.13: Summary of the Results of the Analyses

Economic Parameters	CNG-powered Vehicle Project	Diesel-powered Vehicle Project
Capital Cost, NM	4.31	3.60
Annual Operating Cost, NM	1.47	2.98
Gross Revenue, NM	3.86	3.86
Net Revenue, NM	2.85	1.34
NPV @ 5%, NM	22.19	8.78
NPV @ 10%, NM	15.09	5.41
Internal Rate of Return	24% at 2years	18% at 4 years
Pay-out, yr	1.45	2.7
Price Limit for Profitability, N/liter	N212	N126

4.3 DISCUSSION

The initial capital cost for CNG project amounted to N4.31 million and that for diesel was N3.60 million while the annual operating cost for CNG is N1.47 million and that for diesel is N2.98 million. This difference in the capital costs is basically due to the addition of the extra parts and connections to convert the diesel-powered vehicle to a bi-fuel-powered vehicle which would be able to use CNG as fuel. The difference in the operating costs is due to the fact that the costs of the two fuels are not the same.

The net revenue for CNG is N2.85 million while that for diesel is N1.34 million. This difference in net revenues is resultant from the difference in their gross revenues resultant from the difference in operating costs.

Figs 4.2 and 4.5 represent the time in years against cum-NCR in millions of dollars which was used to determine the pay-out of the projects which is 1.45 yrs for CNG and 2.7 years for diesel respectively.

The NPV and other parameters that make up the project economics were estimated for CNG and diesel. The NPV for CNG at an expected rate of return of 10% is N15.09 million while for diesel, the NPV is N5.41 million, as shown in Tables 4.3 and 4.8 respectively. The IRR for CNG at 2 years and diesel at 4 years were generated as 24% and 18% respectively as shown in Figures 4.1 and 4.4.

The summary of the result of the calculations of all the parameters examined for both CNG and diesel were presented in Table 4.13. From the whole analysis done it is easily seen that using CNG for powering vehicles is more profitable than using diesel.

CNG provides a better fuel service for a driver of an automobile than diesel due to following facts established:

i. The amount of greenhouse gas emissions is less for CNG than for diesel.
ii. CNG is also less flammable than diesel.
iii. The pay-out in years for CNG is less than that of diesel which means that an investor will recover his initial capital faster and breaks even if he invests in CNG-powered vehicles instead of diesel.
iv. The Net Present Value (NPV) in dollars which is a major economic decision indicator for every investor in a project is higher for CNG which makes it more secure.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From the analyses made in this work, it is noted that three major profit indicators where used which include NPV, IRR and Pay out.

The NPV that was obtained for the CNG analysis at different discount rate of 5% and 10% were both positive indicating that the project is profitable and acceptable.

The IRR which is the rate of return that makes the NPV of a cash flow equals zero, tells us how efficient a project is. The IRR obtained from the CNG analysis is very much considerable.

The pay- out period obtained from the CNG analysis is a very short period which makes the investment look very attractive and profitable.

From Fig 4.3, it is shown that if the CNG price goes above N190/liter, then the NPV becomes negative and so it would not be advisable to invest in the CNG project

From Fig 4.4, it is shown that if the diesel price goes higher than N112.7/liter, then the NPV becomes negative and so it would not be advisable to invest in the diesel project.

From all these economic analysis it is proven that the conversion of diesel-powered vehicles to CNG-powered vehicles is more economically viable and profitable than running the vehicles on diesel.

5.2 RECOMMENDATION

The use of CNG for automobiles which has developed a special sub-discipline status of gas technology involved a lot of areas. As this work has successfully confirmed the utilization of CNG for running automobiles and its advantages over the use of diesel, the following areas are also recommended for further studies;

1. Way through which the weight of a CNG -powered vehicle can be reduced to equate with the weight of a diesel-powered vehicle as it is known that the CNG cylinder makes CNG-powered vehicles heavier than diesel-powered vehicles.
2. Further research on the way to rectify the problem of keeping natural gas at very high pressures, close to 4000psi to attain satisfactory driving range with CNG without being troublesome and bringing about additional cost.

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NOMENCLATURE

A = Annual Cost

AGO = Automotive Gas Oil

ANG = Adsorbed natural gas

Bcf = Billion cubic foot

C = Total Capital Cost

CAPEX = Capital Expenditure

CARB = California Air Resources Board

CC = Combustion Chamber

C_{CNG} = CNG Cylinder

CCoE = Chief Controller of Explosives

CH_4 = Methane

C_6H_6 = Benzene

CNG = Compressed natural gas

CO = Carbon monoxide

CO_2 = Carbon dioxide

COS_{CNG} = Fuel Change Over Switch

CUM NCR = Cumulative net cash recovery

EFG = Electric Fuel Gauge

EIA = Energy Information Administration

ER = Electronic Regulator

E&P = Exploration and Production

F_c = Fuel Cost

FP =Final point

gCO_2e/MJ = Grams of CO_2-equivalent per megajoule

GGE = Gallon equivalent

GJ = Gigajoule

GOR = Gas-oil ratio

H_2O = Water

HCNG = CNG mixed with hydrogen

I = Initial Cost of Vehicle

IP = initial point

IRR = Internal Rate of Return

Kg = Kilogram

KJ = Kilojoule

Km = Kilometer

l = Liter

LNG = Liquefied natural gas

LPG = Liquefied petroleum gas

M_c = Maintenance Cost

mm = Millimeter

M_{CNG} = Fuel Mixer

Mscf = Thousand standard cubic foot

MOFs = Metal-organic frameworks

N = Naira

NCR = Net Cash Recovery

NGV = Natural gas vehicle

NM = Million Naira

NO_x = Nitrogen oxides

NPV =Net Present Value

OEV = On-off Electric Valve

OPEX = Operating Expenditure

PM = Particulate matter

PMS= Premium Motor Spirit

PO = Pay-out

PRDs = Pressure relief devices

psi = Pound per square inch

PVs = Present Values

RE = Re-fuelling Electric Valve

REV = Revenue

SO_x = Sulfur oxides

scf = Standard cubic foot

scfm = Standard cubic foot per minute

SV_{CNG} = CNG Solenoid Valve

stb = Stock tank barrel

UHC = Unburned hydrocarbons

US DOE = United States Department of Energy

$ = United States Dollar