

Economic Analysis of Utilising Compressed Natural Gas (CNG) as Vehicular Fuel in Nigeria

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Abstract: Economic analysis of the use of compressed natural gas (CNG) for powering automobiles was presented. The data for costs of constructing and running CNG-powered vehicles were obtained for the study. Economic analysis of running the CNG-powered vehicles was performed. The initial costs of project and operating costs amounted to N3.71million and N1.31million for CNG respectively. The net revenue for CNG is N2.55 million. Figures were used to determine the pay-out of the project which is 1.45 years. The Net Present Value (NPV) and other parameters that make up the project economics were estimated for CNG. The NPV for CNG at an expected rate of return of 10% is N15.7 million. The summary of the result of the calculations of all the parameters examined for CNG was also presented. From the whole analysis done it is easily seen that using CNG for powering vehicles is economically viable.

Keywords: Compressed Natural Gas, Economic Analysis, NPV, Pay-Out, IRR, Automobiles

1. INTRODUCTION

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 [1].

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 [2].

According to Wikimedia Foundation Inc., [3] 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 used in traditional gasoline/internal combustion engine automobiles that have been converted into bi-fuel vehicles (gasoline/CNG). According to Mumtaz,[4] 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 [5]. 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 need to pursue the development of alternative automobile fuel other than petrol and diesel in Nigeria is based on the following associated problems: the rising cost of refined products, such as petrol, diesel, etc; environmental pollution caused by petrol and diesel exhaust fumes; perennial scarcity of

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petrol and diesel due to poor state of Nigerian refineries.

Overtime there has been some level of scarcity of refinery fuels like gasoline and diesel 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 like compressed natural gas (CNG) has sprung up. The main disadvantages of the use of CNG is that it has limited vehicle availability and it is less readily available than gasoline and diesel. The cost of conversion is also 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 [5]).

2. METHODOLOGY

2.1 CONVERTING PETROL/DIESEL-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 diesel-powered vehicles to CNG-powered vehicles are shown in Fig 2.1 below:

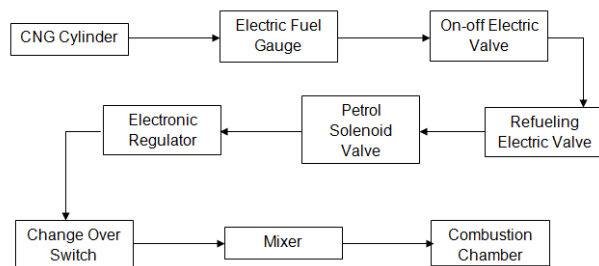


Fig 2.1: Flow Chart of the Installations for Converting Diesel Vehicles to CNG-powered

2.2 OUTPUT OF CNG-POWERED VEHICLES

2.2.1 Heating Values

The heating value of CNG is 1518533 KJ/scf [7].

2.3 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.

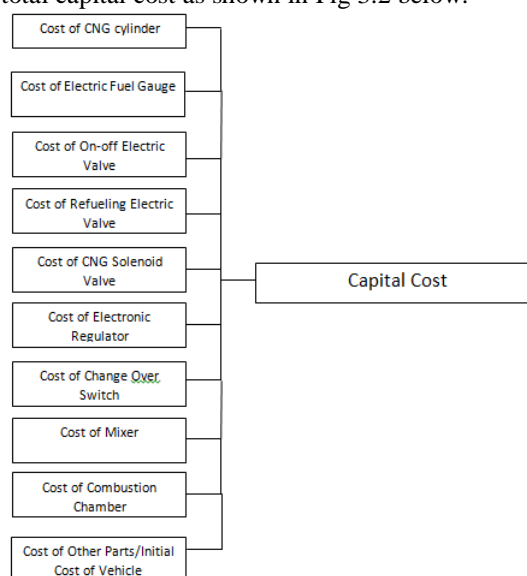


Fig 2.2: Economic flow chart for manufacturing CNG-powered vehicles

Costs Analysis

As in all infrastructural investments in the energy sector, manufacturing CNG-powered vehicles is capital intensive. Investors usually use the return on investment as an indicator 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 [8].

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 of naira to dollar as at April, 2014 is given as:

$$\text{\$1} = \text{N } 161 \quad 2.1$$

Several items contribute to the total investment necessary to put CNG-powered vehicle into operation, as demonstrated in Fig 2.2. 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 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 their car is converted to use 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 [9].

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" [10].

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.

v. Cost of 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. Cost of 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. 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

Gross Revenue = Revenue per km moved * Km covered by the vehicle running on the available

volume of CNG

2.3

Net revenue for subsequent years of operation =

Gross revenue – Annual Operating cost

2.4

3. RESULT

The heating values and prices of CNG are as shown in Table 3.1 below:

Table 3.1: Heating Values and Prices of CNG [7]

Heating Value	1518533 KJ/scf
Price	\$0.38/l

3.1 Economic Analysis of CNG-Powered Vehicle

3.1.1 Costs Analyses for CNG-powered Vehicle

3.1.1.1 Total Capital Cost, (C)

3.1.1.1.1 Initial Cost of Vehicle, (I)

The cost of procuring a diesel-powered vehicle is \$20000 = N3.2 million

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

The cost of installing the CNG cylinder and its accessories is \$280 = N45080

3.1.1.1.3 Cost of Electric Fuel Gauge, (EFG)

The installation of electric fuel gauge is set at \$59.38 = N9560

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

The cost of buying and installing the on-off electric valve is \$1000 = N161000

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

The cost of installing the re-fuelling valve is \$800 = N128800

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

The installation of the CNG solenoid valve is set at \$500 = N80500

3.1.1.1.7 Cost of the Electronic Regulator, (ER)

The cost of buying and installing electronic regulator is \$100 = N16100

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

The cost of installing the fuel change over switch is \$200 = N32200

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

The installation of fuel mixer is set at \$10 = N1610

3.1.1.1.10 Cost of Installing Combustion Chamber, (CC)

The cost of installing the combustion chamber and Valve is \$1000 = N161000

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

3.1

Total Capital Cost (C) = \$23049.38 = N3.71 million

3.1.1.2 Annual Cost, (A)

3.1.1.2.1 Fuel Cost, (F_c)

According to Watt [11], the average kilometer per liter covered by a vehicle running on CNG is 1.66km/l. A vehicle that plies 93km to and fro within south-east, Nigeria 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 that 93km 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 = N1.23 million

3.1.1.2.2 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 N77280 annually.

Annual Cost, A = F_c + M_c = \$7664 + \$480 = \$8144 = N1.31 million

3.1.2 Revenue Analyses for CNG-powered Vehicles

If the revenue the vehicle earns for one trip of 93km and back is \$133, then Gross Revenue = \$133 * 15 * 12 = \$24000.

Annual Net Revenue = \$24000 – \$8144 = \$15856 = N2.38 million

3.1.3 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 [12].

The cash flows in dollars for the CNG-powered vehicle project over the space of 15 years is shown in Table 3.2 and also the cash flows in millions of Naira

for the CNG-powered vehicle project over the space of 15 years is shown in Table 3.3:

Table 3.2: Cash Flows for the CNG Vehicle Project over the space of 15 years

Time (yr)	CAPEX (\$)	OPEX (\$)	GROSS REV (\$)	NCR (\$)	CUM NCR (\$)	PV @ 5% (\$)	PV @ 10% (\$)
0	23049	0	0	(23049)	(23049)	(23049)	(23049)
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

Table 3.3: 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	3.71	0.00	0.00	(3.71)	(3.71)	(3.71)	(3.71)
1	0.00	1.31	3.86	2.55	(1.16)	2.43	2.32
2	0.00	1.31	3.86	2.55	1.39	2.32	2.11
3	0.00	1.31	3.86	2.55	3.95	2.21	1.92
4	0.00	1.31	3.86	2.55	6.50	2.10	1.74
5	0.00	1.31	3.86	2.55	9.05	2.00	1.59
6	0.00	1.31	3.86	2.55	11.61	1.90	1.44
7	0.00	1.31	3.86	2.55	14.16	1.81	1.31
8	0.00	1.31	3.86	2.55	16.71	1.73	1.19
9	0.00	1.31	3.86	2.55	19.26	1.65	1.08
10	0.00	1.31	3.86	2.55	21.82	1.57	0.98
11	0.00	1.31	3.86	2.55	24.37	1.49	0.89
12	0.00	1.31	3.86	2.55	26.92	1.42	0.81
13	0.00	1.31	3.86	2.55	29.48	1.35	0.74
14	0.00	1.31	3.86	2.55	32.03	1.29	0.67
15	0.00	1.31	3.86	2.55	34.58	1.23	0.61

From Table 3.2, 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 = N22.79 million
The NPV at a discount rate of 10% = \$97553 = N15.71 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 3.3 is another table generated from Table 3.2 and it

shows the cash flows for the project over 2 years. The essence of Table 3.4 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, few number of years, like 2 to 4 years, is applied in generating the IRR rather than many number of years. Table 3.4 is shown below:

Table 3.4: Cash Flows for the CNG Vehicle Project over the space of 2 years

Time (yr)	CAPEX (\$)	OPEX (\$)	GROSS REV (\$)	NCR (\$)	CUM NCR (\$)	PV @ 5% (\$)	PV @ 10% (\$)
0	23049	0	0	(23049)	(23049)	(23049)	(23049)
1	0	8144	24000	15856	(7193)	15101	14415
2	0	8144	24000	15856	8663	14382	13104

Table 3.5 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 3.1 for the determination of the IRR which is 24%. The 24% is the discount rate at which the NPV equals zero.

Table 3.5: 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)

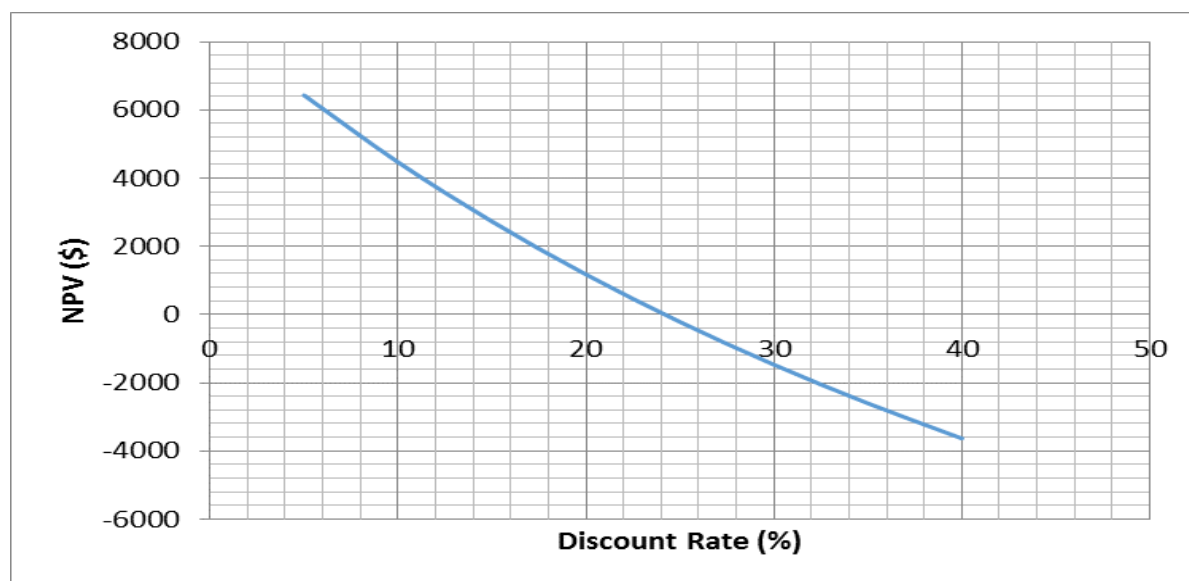


Fig 3.1: Plot of NPV against Discount Rate

3.1.4 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 3.6 shows the cumulative NCR and NCR after 7 years while Fig 3.2 represents the graph of time against cumulative NCR in billions of dollars for the CNG-powered vehicle project.

Table 3.6: Cum NCR after 7 years

Time (yr)	NCR (\$)	CUM NCR (\$)
0	(23049)	(23049)
1	15856	(7193)
2	15856	8663
3	15856	24519
4	15856	40375
5	15856	56231
6	15856	72087
7	15856	87943

From Fig 3.2, 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:

$$(PO - IP) / (FP - IP) = (0 - \text{CUM NCR at IP}) / (\text{CUM NCR at FP} - \text{CUM NCR at IP})$$

3.2

$$(PO - 1\text{yr}) / (2\text{yrs} - 1\text{yr}) = (0 - (-7193)) / (8663 - (-7193))$$

PO = 1.45yrs as indicated in Fig. 3.2.

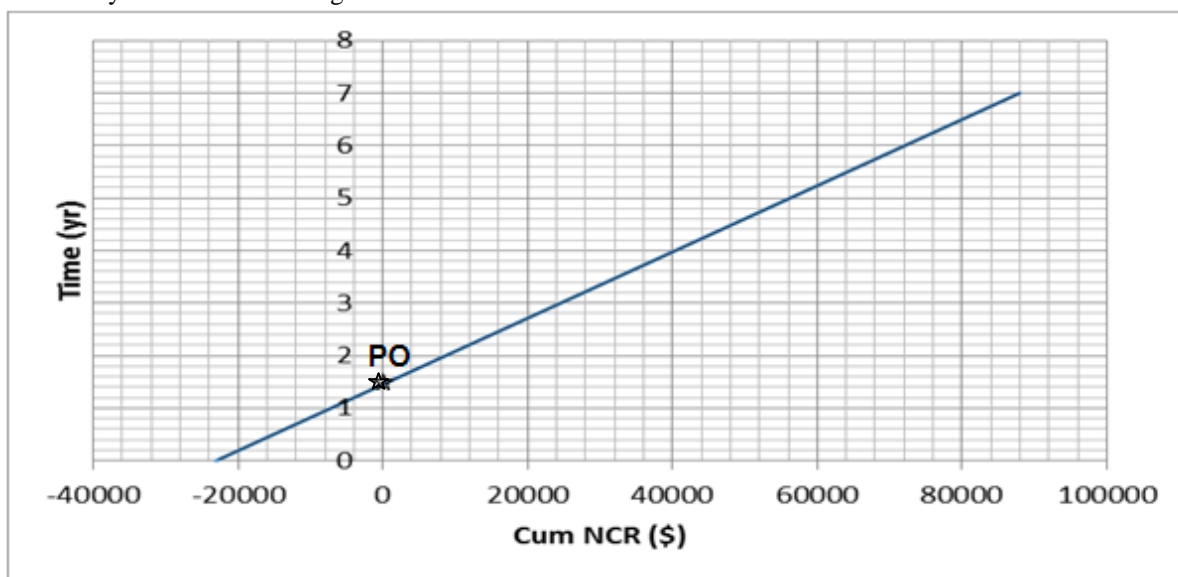


Fig 3.2: Plot of Time (yr) against Cum NCR (\$)

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

The NPV after 4 years at various CNG prices are as shown in Table 3.7 which was used to plot a chart of NPV (\$) against CNG Price (\$/l) as shown in Fig 3.3.

From Fig 3.3, if CNG price goes higher than \$1.18 per liter ie N190 per liter, then the NPV becomes negative and so it would not be advisable to invest in the CNG-powered vehicle project.

Table 3.7: 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)

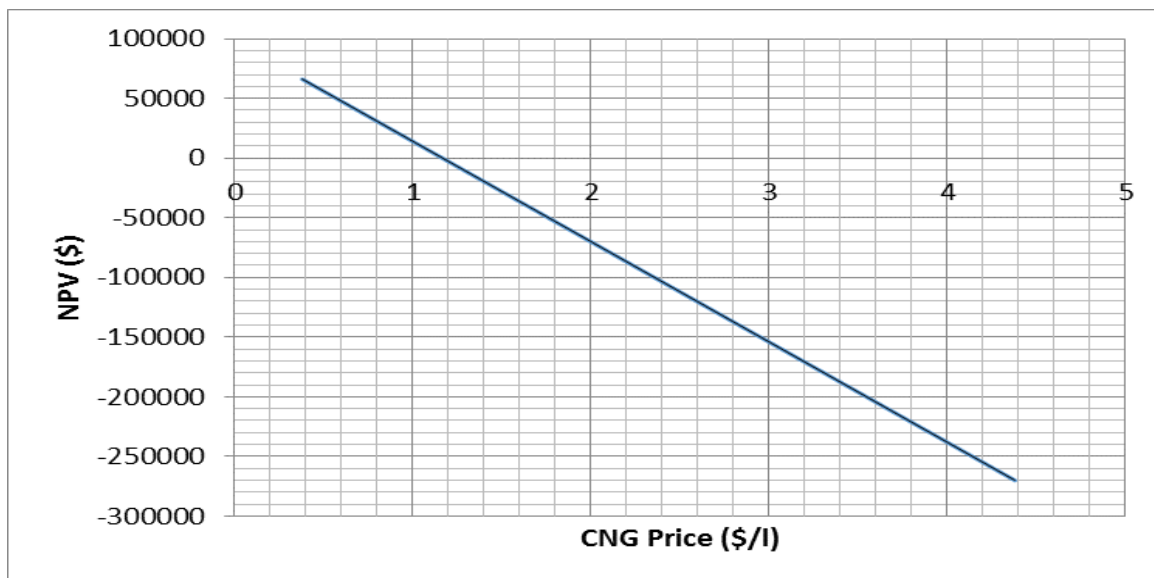


Fig 3.3: Plot of NPV (\$) against CNG Price (\$/l)

Table 3.13: Summary of the Results of the Analyses

Economic Parameters	
Capital Cost, NM	3.71
Annual Operating Cost, NM	1.31
Gross Revenue, NM	3.86
Net Revenue, NM	2.55
NPV @ 5%, NM	22.79
NPV @ 10%, NM	15.71
Internal Rate of Return	24% at 2years
Pay-out, yr	1.45
Price Limit for Profitability, N/liter	N190

4. CONCLUSION

Three profit indicators: NPV, IRR and Pay out were employed in this work for the economic analyses.

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

At the end of the analyses, it is proven that it is economically viable to utilize CNG as vehicular fuel in Nigeria.

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NOMENCLATURE

A = Annual Cost
Bcf = Billion cubic foot
C = Total Capital Cost
CAPEX = Capital Expenditure
CC = Combustion Chamber
C_{CNG} = CNG Cylinder
CCoE = Chief Controller of Explosives
CNG = Compressed natural gas
COS_{CNG} = Fuel Change Over Switch
CUM NCR = Cumulative net cash recovery

EFG = Electric Fuel Gauge
EIA = Energy Information Administration
ER = Electronic Regulator
F_c = Fuel Cost
FP = Final point
GJ = Gigajoule
I = Initial Cost of Vehicle
IP = initial point
IRR = Internal Rate of Return
Kg = Kilogram
KJ = Kilojoule
Km = Kilometer
l = Liter
M_c = Maintenance Cost
M_{CNG} = Fuel Mixer
Mscf = Thousand standard cubic foot
N = Naira
NCR = Net Cash Recovery
NM = Million Naira
NPV = Net Present Value
OEV = On-off Electric Valve
OPEX = Operating Expenditure
PO = Pay-out
PRDs = Pressure relief devices
PVs = Present Values
RE = Re-fuelling Electric Valve
REV = Revenue
scf = Standard cubic foot
SV_{CNG} = CNG Solenoid Valve
stb = Stock tank barrel
US DOE = United States Department of Energy
\$ = United States Dollar