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RESEARCH ARTICLE

APPLICATION OF CNG-P, A NEWLY DEVELOPED SOFTWARE FOR THE ECONOMIC ANALYSIS OF THE USE OF CNG VEHICLES AS MEANS OF PUBLIC TRANSPORTATION IN NIGERIA.

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Abstract

Economic Analysis of the use of CNG Vehicles as means of Public Transportation in Nigeria using CNG-P, a Newly Developed Software is presented in this work. Port Harcourt – Onitsha expressway is taken as case. This involves analysis on collection of gas from the sales point which is taken as a treatment plant about 10km off the route, through the pipelines to the sites of the CNG refueling stations which would be installed along the route to refill the vehicles. CNG-P was developed and used to conduct economic analysis of the project. The economic parameters determined with CNG-P are: capital costs; operating costs; gross revenue; net revenue; net present value; and profit per Naira invested. From the analysis, the project is found to be very economically viable as it generates high net present value of \$829million and profit per Naira invested of 0.72. When compared with the results got by doing the analysis manually, the results got using CNG-P were found to correlate to a very high degree with the results got by performing the calculations manually. This new software is an excellent contribution to knowledge as it would make it much simpler for gas operators who wish to invest in CNG vehicles project to take well-balanced economic decisions.

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Introduction:-

1.1 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 (Anyadiegwu et al, 2017).

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 (California Energy Commission, 2013).

According to Wikimedia (2017), compressed natural gas (CNG) (methane stored at high pressure) is a fuel which can be used in place of gasoline (petrol), diesel fuel and propane/LPG. CNG combustion produces fewer undesirable gases than the fuels mentioned above. It is safer than other fuels in the event of a spill, because natural gas is lighter than air and disperses quickly when released. CNG may be found above oil deposits, or may be collected from landfills or wastewater treatment plants where it is known as biogas. CNG is made by compressing natural gas (which is mainly composed of methane, CH_4), to less than 1 percent of the volume it occupies at standard atmospheric pressure. It is stored and distributed in hard containers at a pressure of 20–25 MPa (2,900–3,600 psi), usually in cylindrical or spherical shapes. CNG is used in traditional gasoline/internal combustion engine automobiles that have been modified or in vehicles which were manufactured for CNG use, either alone ('dedicated'), with a segregated gasoline system to extend range (dual fuel) or in conjunction with another fuel such as diesel (bi-fuel).

According to Allen (1999), in Africa, Egypt had 128,754 CNG vehicles and 124 CNG fueling stations. Egypt was also the first nation in Africa and the Middle East to open a public CNG fueling station in January 1996.

1.2 CNG Refueling Stations

According to US DOE (2017), unlike gasoline or diesel stations, compressed natural gas stations (CNG) 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 fuelled. Making the right choices about the size of compressor and the amount of storage at the station will impact the cost of fuel and range for vehicles.

There are two types of CNG infrastructure: time-fill and fast-fill. The main structural differences between the two systems are the amount of storage capacity available and the size of the compressor. These factors determine the amount of fuel dispensed and time it takes for CNG to be delivered.

Fast-fill:

Generally, fast-fill stations are best suited for retail situations where vehicles arrive randomly and need to fill up quickly. For a station serving light-duty vehicles, the space needed to store the equipment measures about the size of a parking space. Fast-fill stations receive fuel from a local utility line at a low pressure and then use a compressor on site to compress the gas to a high pressure. Once compressed, the CNG moves to a series of storage vessels so the fuel is available for a quick fill-up. CNG can also be delivered via dispensers alongside gasoline or other alternative fuels dispensers. This is represented in Figure 1.1 below.

Drivers fuelling light-duty vehicles at a fast-fill station experience similar fill times to a conventional gasoline fuelling station—less than 5 minutes for a 20 gallon equivalent tank. Large truck and bus stations will fill at twice that rate. CNG at fast-fill stations is often stored in the vessels at a high service pressure (4,300 psi), so it can deliver fuel to a vehicle quickly. The dispenser uses sensors to calculate pressure and measure the number of GGEs delivered to the tank, taking temperature into account.

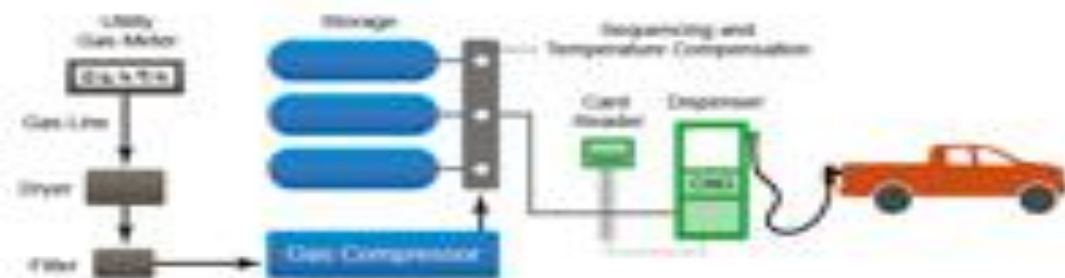


Fig 1.1:-Fast-Fill CNG Station

Time-fill:

Time-fill stations are used primarily by fleets and work best for vehicles with large tanks that refuel at a central location every night. At a time-fill station, a fuel line from a utility delivers CNG at a low pressure to a compressor on site. Unlike fast-fill stations, vehicles at time-fill stations are generally filled directly from the compressor, not from fuel stored in high pressure vessels. The size of the compressor needed depends on the size of the fleet. Although there is a small buffer storage tank, its purpose is not to fill vehicles, but to keep the compressor from turning off and on unnecessarily—wasting electricity and causing undue wear and tear on the compressor. The storage vessels are sometimes used to "top off" vehicle tanks during the day.

The time it takes to fuel a vehicle depends on the number of vehicles, compressor size, and the amount of buffer storage. Vehicles may take several minutes to many hours to fill. The advantage of using a time-fill station is that the heat of recompression is less than, so you usually get a fuller fill than with a fast-fill station. Also, with a time-fill station you can control when you fill the vehicles. This means you can choose to run the compressor during off-peak hours (like at night) to achieve lower electricity rates. Figure 1.2 shows a Time-fill station.

Time-fill stations are carefully architected based on the application they will be used for. For example, a transit bus company may need a larger compressor that can deliver 8 to 9 gallons per minute, while a refuse truck company can make due filling trucks at 3 gallons per minute using a smaller compressor. A consumer application may require far less—such as less than half of a gallon an hour. These differences account for the large variance in the cost of installation.

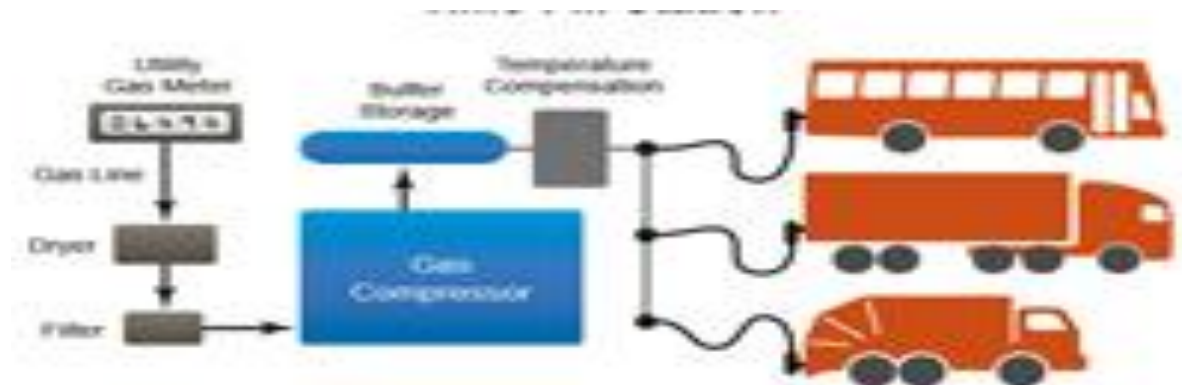


Fig 1.2:-Time-Fill CNG Station

From the illustrations of the Fast-fill and Time-fill stations, it is seen that Fast-fill stations are the preferred option for the CNG project in Nigeria since vehicles would have to arrive randomly and need to fill up quickly

Review Of Literature On Natural Gas Utilization

2.1 Nigeria's Natural Gas Utilization

Out of estimated 5 bcf/day of gas productions in Nigeria, about 17% is re-injected, 33% is used for commercial purposes and the remaining 50% is flared (Izuwa, 2017). This remaining unused gas can be converted to electricity, vehicular fuel and natural gas hydrate (Izuwa, 2015). Therefore, development and effective management of gas sector in Nigeria remains a strong channel for expansion and will generate opportunity for multiple revenues for Nigerian economy (Izuwa, 2017). Natural gas is a valuable fuel with increasing demand as the desire for clean and environmentally friendly fuel is required (Izuwa, 2015).

Natural gas liquid (NGL) is used in the industrial sector as a fuel for process heating as well as feedstock (or raw material) for the production of chemicals (such as NH_3 , methanol—used in the manufacture of many polymers, butane, ethane, propane, hydrogen, and acetic acid). It is also an ingredient for the production of fertilizer, antifreeze, plastics, pharmaceuticals and fabrics. In the electric power sector, natural gas is used to generate electricity (US Energy Information Administration, 2016). Naqvi, (2014) analyzed the economic aspects of natural gas when used as gaseous fuel in the energy industry by evaluating four options – Ammonia production, using the Uhde Dual-Pressure Process, Fuel production by Fischer-Tropsch Process, Liquefied Gas Production, using the Mixed-Refrigerant Process, and Methanol production, using Johnson Matthey Combined Reforming Process. The

analysis showed that among the four options, methanol production was the most lucrative option for gas-related investments in the United States under the current circumstances, which includes gas price, current gas supply and potential of future gas supply.

2.2 Worldwide Use Of Cng Vehicles

There are so many CNG vehicles available currently. The buzz on alternatives to gasoline usually focuses on electrics, hybrids, or ethanol. But Honda pushed another alternative: a Civic that runs on compressed natural gas (CNG). The natural gas Civic has been offered in fleet sales since 1998, and customers in California and certain other states since 2005. Honda rolled its latest CNG sedan out nationwide for 2012, based on the current Civic (Consumer Reports, 2014). The CNG cylinder (fuel tank) is carried in the trunk of the car and holds 8.0 gasoline gallon equivalent (GGE) at 3600psi (Honda, 2012). Range on a full 3600psi fill is variable, depending on driving conditions and driving technique. Honda claims an estimated 225–250 miles from a full CNG tank (Honda, 2007).

GM do Brasil introduced the MultiPower engine in 2004, which was capable of using CNG, alcohol and gasoline (E20-E25 blend) as fuel, and it was used in the Chevrolet Astra 2.0 model 2005, aimed at the taxi market (GNVNews, 2006).

Other CNG Vehicles available are Chevrolet G4500 or Ford E-450 chassis which may be converted to use CNG or propane (US DOE, 2017a). There are so many more CNG vehicles in existence presently which cannot all be outlined in this work. The CNG vehicles that would ply the road can be bought by Nigeria from these vehicle manufacturers and shipped down here. Another option can be to convert some existing diesel and petrol vehicles to CNG vehicles done by Qualified Service Retrofitters (QSRs).

CNG vehicles and fuelling stations are not very common in Nigeria. In this work, the project of introducing CNG vehicles and installing CNG fuelling stations in major places in Nigeria is studied. The major road used as case for the project is Port Harcourt to Onitsha Expressway.

2.3 Current Status of CNG Development in Nigeria

Igweonu and Mbabuike (2011) made a case for utilization of Compressed Natural Gas (CNG) for automobiles in Nigeria. They argued that the issues that make it important are safety, affordability (fuel pricing), environmental and regulatory requirements as well as distribution network. They found out that at present, CNG provides fuel for more than eleven million natural gas vehicles (NGVs) on the road globally, with Pakistan (often referred to as a ‘gas-based economy’) alone accounting for about 2.2 million. Oando is the developer of Nigeria’s foremost natural gas distribution network. In 1999, Unipetrol acquired 40 per cent equity of Gas-link to utilize its exclusive gas sale and purchase agreement with the Nigeria Gas company (NGC). They delivered the first gas to Cadbury Nigeria Plc at Ikeja, Lagos, in 2000. The Gaslink Ikeja 1A pipeline expansion project was completed in 2001; and Ikeja 1B pipeline expansion project was completed in 2002. In 2004 Gaslink’s Greater Lagos (GL) II Pipeline-expansion project was completed. Gaius-Obaseki (2001) reviewed the evolution of the use of CNG in Nigeria and stated that the Nigerian Gas Company (NGC) has been in the vanguard for the development of CNG vehicles in Nigeria. It elevated the profile of natural gas to a level of considerable relevance in the local Nigerian energy mix, including venturing into frontier areas of compression of natural gas and its utilization. NGC had at a time embarked on a pilot scheme with a view to ascertaining the technical and commercial viability as an automotive fuel and an alternative to gasoline. It embarked upon the CNG scheme in 1989 on a pilot basis to promote CNG as an automotive fuel. It installed a CNG conversion workshop with cylinder test rig in its Warri office.

Methodology:-

3.1 Development of Natural Gas as Transportation Fuel

Natural gas is transformed to automotive transportation fuel using compression equipment. The procedure employed in the development of natural gas as transportation fuel comprises:

1. Determination of the gasoline gallon equivalent (GGE) requirement of the CNG vehicles to enable the quantity of CNG utilization to be known.
2. Design of pipeline network and refueling stations to be installed.
3. Laying of natural gas pipelines from gas supply (gas gathering) plants from the oil and gas fields to the sites where the CNG refuelling stations would be sited.

The route used as case for the project is Port Harcourt to Onitsha Expressway. CNG refuelling stations would have to be installed along the expressway while gas pipelines are laid across to transport gas to the CNG refuelling stations where it would be compressed and stored for refuelling the CNG vehicles that would ply the route.

3.2 Evaluation of the Economic Viability of the CNG Transportation Project

The essence of conducting the economic appraisal is to determine whether the project is economically viable to be invested in or not. The necessary costs include the capital costs and the annual costs.

3.2.1 Costs and Revenue Analyses

Several items contribute to the total investment necessary to put CNG-powered vehicle into operation. They include:

Costs of Pipeline and Compressor Station (C_{PC}):

These include the cost of laying the pipeline from the sales point to the locations of the CNG refueling stations and the cost of the compressor that would be installed at the initial point of the pipeline. The pipeline would be laid in such a way that one pipeline would be able to supply gas to the entire CNG refueling stations that would be installed along the Port Harcourt - Onitsha Expressway.

Compressor station:

A reciprocating compressor of less than 1000 hp for which daily input / output is up to 500 MScf/day is chosen.

Pipelines and metering stations:

Pipe segments with average length of 20 miles and diameters of 12 inches, 14 inches or 18 inches that can cover the length of about 120 miles are commonly used, and metering stations are installed. Different pipes of lengths up to 40ft make up the various pipe segments (Oilserve Nigeria Limited, 2004).

Costs of pipelines and compressor station can be estimated as:

$$C_{PC} = C_{PC \text{ per km}} * L \quad 3.1$$

Where C_{PC} per km = costs of pipeline and compressor station per km

L = pipe length

Cost of CNG Refuelling Stations (C_{CR}):

This includes the cost of purchasing and installing the CNG refuelling stations with their associated compressor stations along Port Harcourt-Onitsha Expressway. The number and storage capacity of the CNG refuelling stations depend on the number of vehicles that ply the route in a given time. Cost of CNG refuelling stations can be estimated as:

$$C_{CR} = C_{CR \text{ per station}} * N_{CS} \quad 3.2$$

Where N_{CS} = number of CNG refueling stations

Cost of CNG Vehicles (C_{CV}):

This is the total cost of the CNG vehicles that would be purchased and shipped down to Nigeria which would be plying Port Harcourt-Onitsha Expressway. It is assumed that the vehicles would be purchased on a one-time basis and they would have life span of seven (7) years each before they are discarded as scrap. Cost of CNG vehicles can be estimated as:

$$C_{CV} = C_{CV \text{ per vehicle}} * N_V \quad 3.3$$

Where N_V = number of vehicles plying the route from Port Harcourt - Onitsha

The total Capital Cost, CAPEX is given by:

$$T_{CC} = C_{PC} + C_{CR} + C_{CV} \quad 3.4$$

Annual Operating cost, OPEX is given by:

$$A_{OC} = G_{AC} + R_{FML} + M_{PC} + V_{DAC} \quad 3.5$$

Where, G_{AC} = Annual Cost of Gas

R_{FML} = Fuel, Maintenance and Labour Costs for CNG Refueling Stations

M_{PC} = Maintenance Costs for Pipelines and Compressors

V_{DAC} = CNG Vehicles Drivers and Assistant Drivers' Wages and Car Maintenance Costs

According to United States Department of Energy (2016), one GGE equals 126 Scf of natural gas at pressure of 30psia. The price of natural gas is N1640/MScf (\$4/MScf) (Rapu et al, 2015). Annual cost of gas is estimated as:

$$A_{CG} = L_{GGE} * 126 * G_p * 353 \quad 3.6$$

Where G_p = Price of natural gas \$0.004/scf

L_{GGE} = GGE requirement for light duty vehicle

353 = Number of plying days of the vehicles considering 12 days of routine maintenance of the vehicles per year.

Fuel, maintenance and labour costs for CNG refuelling stations (R_{FML}) are estimated as 13% of the costs of CNG refuelling stations as (Smith et al, 2014):

$$R_{FML} = 0.13 * C_{CR} \quad 3.7$$

According to Cornot-Gandolphe et al, (2003), maintenance costs for pipelines and compressors are estimated as 20% of the costs of pipelines and compressor stations per km as shown:

$$M_{PC} = 0.2 * C_{PC} \quad 3.8$$

According to Consumer Reports, (2014), CNG vehicle drivers and assistant drivers' wages and car maintenance costs are determined as 24 per cent of gross revenue as:

$$V_{DAC} = 0.24 * GR \quad 3.9$$

$$\text{Gross Revenue, } GR = V_{freq} * N_V * VP_C * TF * 353 \quad 3.10$$

Where, V_{freq} = Frequency of Transportation per day per Vehicle

N_V = Total Number of Vehicles

VP_C = Total Number of Passengers per Vehicle

TF = Transport Fare of each Passenger

353 = Number of plying days of the vehicles considering 12 days of routine maintenance of the vehicles per year.

Net revenue for subsequent years of operation,

$$NR = GR - OPEX \quad 3.11$$

3.2.2 Net Present Value (NPV)

Net Present Value (NPV) is a measure of profitability of any project. The net present value (NPV) or net present worth (NPW) of a time series of cash flows, both incoming and outgoing, is defined as the sum of the present values (PVs) of the individual cash flows. NPV compares the value of a Naira today to the value of that same Naira in the future, taking inflation and returns into account. If the NPV of a prospective project is positive, it should be accepted. However, if NPV is negative, the project should be rejected because cash flows will also be negative (Anyadiiegwu, 2012).

NPV =

$$PV \text{ at } 1\text{yr} + PV \text{ at } 2\text{yrs} + PV \text{ at } 3\text{yrs} + PV \text{ at } 4\text{yrs} + PV \text{ at } 5\text{yrs} + PV \text{ at } 6\text{yrs} + PV \text{ at } 7\text{yrs} - PV \text{ at } 0\text{yr} \quad 3.12$$

3.2.3 Profit per Naira Invested

The profit per Naira of a project refers to the amount of profit generated by the project per unit expenditure on the project. It is an economic indicator used to predict or evaluate how economically viable the project is. A high profit per Naira (P/N) value means that the project is highly economically viable and vice versa. P/N of a project is estimated as a function of the total net cash recovery over a period of time and the sum of the CAPEX and OPEX. In this section, the P/N after 7years is the ratio of the total net cash recovery from the first (1st) to seventh (7th) year and the sum of CAPEX and OPEX as represented below:

$$P/N = NCR_{total} / [(CAPEX + (OPEX * 7))] \quad 3.13$$

Where NCR_{total} = total net cash recovery of the project for the 7 years

3.3 Development of CNG-P Software for the Economic Evaluation

Microsoft Excel - Visual Basic program (Excel-VBA) was used for the development of software for the economic evaluation of compressed natural gas as an alternative fuel for automobiles in Nigeria. The name of the software is CNG-P. The economic analysis is conducted using the developed Microsoft-Excel Visual Basic program. A sample of the input interface for the program is as shown in Figure 3.1 below.

CNG-P INPUT

ROUTE PARAMETERS

Route Distance between the Two Towns, km

Distance from Gas Sales Point to Route, km

Estimated Daily Number of Vehicles Travelling from One Town to the Other

CLASS OF VEHICLES

☒ Light Duty Vehicles ☐ Heavy Duty Vehicles

SUPPLY GAS AND PIPELINE PARAMETERS

Gas Specific Gravity Gas Temperature, deg F

Gas Z-Factor Gas Pipeline Diameter, in

ECONOMICS

Price of Gas, \$/scf CNG Station Cost, \$

CNG Vehicle Price, \$ Pipe Systems Cost, \$/km

Vehicle Revenue/Trip, \$ Rate of Discount, %

Evaluate **Clear** **Exit**

Fig 3.1:-Input Interface of CNG-P

Presentation Of Results:-

4.1 Application of CNG-P for the Analysis of the CNG Automobile Transportation Project

The newly developed software, CNG-P was used to perform the economic analysis of the use of CNG vehicles for transportation in Nigeria. This was done by feeding the required data into CNG-P for the evaluation of the required parameters. The input interface of this analysis is as shown in Figure 4.1.

CNG-P INPUT ×

ROUTE PARAMETERS

Route Distance between the Two Towns, km

194

Distance from Gas Sales Point to Route, km

10

Estimated Daily Number of Vehicles Travelling from One Town to the Other

800

CLASS OF VEHICLES

☒ Light Duty Vehicles
☐ Heavy Duty Vehicles

SUPPLY GAS AND PIPELINE PARAMETERS

Gas Specific Gravity

0.69

Gas Temperature, deg F

179.9

Gas Z-Factor

0.92

Gas Pipeline Diameter, in

12

ECONOMICS

Price of Gas, \$/scf

0.004

CNG Station Cost, \$

900000

CNG Vehicle Price, \$

27000

Pipe Systems Cost, \$/km

700

Vehicle Revenue/Trip, \$

23.01

Rate of Discount, %

10

Evaluate

Clear

Exit

Fig 4.1:-Input Interface for the Economic Analysis of the Project using CNG-P

The results of the economic analysis are shown in Table 4.1.

Table 4.1:-Results of the Economic Analysis using CNG-P

ECONOMICS	
CAPITAL EXPENDITURE (NAIRA)	5636622000
ANNUAL OPERATING COST (NAIRA)	1043523666
GROSS REVENUE AT FIRST YEAR (NAIRA)	2371778760
NET REVENUE AT FIRST YEAR (NAIRA)	1328255094
NET PRESENT VALUE AFTER 7 YEARS (NAIRA)	829880096
PROFIT PER NAIRA INVESTED	0.72

4.2 Comparison of the CNG-P Results with Manual Calculation Results

Performing the analyses manually would yield the results shown together with the CNG-P results in Table 4.2.

Table 4.2:-Results of the Economic Analyses using CNG-P and Manual Calculation

ECONOMICS		
	CNG-P Results	Manual Calc Results
CAPITAL EXPENDITURE (NAIRA)	5636622000	5635000000
ANNUAL OPERATING COST (NAIRA)	1043523666	1044000000
GROSS REVENUE AT FIRST YEAR (NAIRA)	2371778760	2372500000
NET REVENUE AT FIRST YEAR (NAIRA)	1328255094	1330000000
NET PRESENT VALUE AFTER 7 YEARS (NAIRA)	829880096	830000000
PROFIT PER NAIRA INVESTED	0.72	0.72

Conclusions:-

Economic Analysis of the use of CNG Vehicles as means of Public Transportation in Nigeria using CNG-P, a Newly Developed Software was conducted in this work. From the analyses conducted, the following conclusions can be drawn:

1. The introduction of the use of CNG vehicles as means of public transportation is very economically demanding, as it requires very large investment cost of over \$5.6billion.

2. The use of CNG vehicles as means of public transportation in Nigeria would be a highly economically viable project as the analysis in this work shows that it would give a high net present value of \$829million and profit per Naira invested of 0.72.
3. CNG-P is a very reliable software for economic analyses of the CNG project as the results corresponded with the manual calculation results.
4. This new software would make it much simpler for gas operators who wish to invest in CNG vehicles project to take well-balanced economic decisions.

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