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A Review on Natural Gas Utilization and Cutting Carbon Emissions: How viable is Compressed Natural Gas for Road Vehicle Fuel?

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Abstract
As the world grows and economies develop, global demand for energy will continue to grow dramatically. Demand for natural gas is likely to overtake other fossil fuels due to its availability, accessibility, versatility and cleanliness. For instance, the International
Energy Agency (IEA) proposed in May 2012 that global demand for natural gas could rise more than 50% by 2035, from 2010 levels. According to the Intergovernmental Panel on Climate Change (IPCC), global greenhouse gas (GHG) emissions must be reduced by 50 to 80 percent by 2050 to avoid dramatic consequences of global warming. In order to meet this growing energy demand and GHG reduction, we must develop all commercially-viable energy sources. As we know that no single energy source can meet the world's growing energy needs. We also need a more diverse energy mix which will enable energy security and help tackle the issue of climate change. Meeting this growing long-term societal demand requires that we develop all economic and environmentally-sound energy sources. Natural gas which is the cleanest compared to other fossil fuels is available to provide the world with a viable alternative. Its abundance, reliability, versatility and accessibility, will be a huge factor. This paper considers the value of compressed natural gas (CNG) to be used for natural gas vehicles (NGV), and how it could serve as a long-term emission-reducing energy source. Such uptake would also improve utilisation of natural gas instead of flaring it, thereby minimizing environmental harm and improving public safety.
Keywords: Compressed Natural Gas (CNG), Natural Gas Vehicles (NGV), Green House Gas (GHG), Cash Flow Analysis of CNG

1. The Alternative Sources

. Alternative energy sources are divided into the categories of non-renewable energy sources, e.g. natural gas**;** and renewable energy sources, e.g. solar energy. Alternative energies has been known to be economical, and environmentally friendly.

Table 1 Criteria Affecting the Suitability of Alternative Fuel.

Item	Criteria
Availability	Production facilities, pre-existing infrastructure and the natural resources as raw material in the form of fossil fuels.
Economics	The fuel production & distribution cost, the cost of constructing new facilities, cost of raw material used, and the cost of retrofitting old equipment to process the new fuel or to replace them with new technology.
Acceptability	Inherently safe in handling and refueling and also inherent health risks to humans or animal life.
Environmental & Emissions	Reduce fuel effect to global warming & if in the event of large scales release, it must be.
National security	The material must readily available and process without reliance on foreign materials.
Technology	Must be commercially available & emerging technology available to process the fuel in commercial quamgtities.
Versatility	It must be versatile in application & can be manufactured using various feedstock.

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

2. Fossil Fuels

Despite much that is said and written, fossil fuels will remain the major contributor to the energy mix for many years to come. Their relative availability, affordability, efficiency and versatility make them indispensable. Coal of course produces more carbon than any other fossil fuel. To give you an example: it accounts for around 50% of America's power generation but accounts for 80% of the resulting carbon emissions (Hayward, 2009). Crude oil discoveries are on the decline. This means that natural gas is bound to become far more important in the world economy. The only one way of achieving this is by increasing the utilisation of natural gas. It's efficient, versatile and abundantly available. There are reserves in place equivalent to 63.6 years worth of consumption at current rates (Leather, Bahadori, Nwaoha and Wood, 2013). For example, Nigeria's proven reserve at 180 Trillion Cubic Feet and bulk of the gas reserves are located in the Niger Delta (Nwaoha, 2010).

Demand for natural gas is likely to overtake other fossil fuels due to its availability, accessibility, versatility and smaller environmental footprint. For example, the International
Energy Agency (IEA) proposed in May 2012 that global demand for natural gas could rise more than 50% by 2035, from 2010 levels (Wood, Nwaoha and Towler, 2012).
Although natural gas is abundant, more than one-third of global reserves are classified as stranded (Economides and Mokhatab,2007). The global consumption of natural gas has been increasing at a very rapid pace. Worldwide consumption of natural gas is forecast to double by 2030 (Vivek, 2012). The developing economies of Asia, Latin America, and Africa, which have relatively recently discovered the magic of natural gas, will show the highest growth rates. The greatest total volume increases will be in the developed economies of Europe, North Asia, and Asia, which have used natural gas for decades (Vivek, 2012). Global natural gas production was pegged at 3.3 tcm in 2010 with the IEA forecasting that it will potentially rise to some 4.0 tcm in 2012 and to 5.1 tcm in 2035 (Wood, Nwaoha and Towler, 2012).

The growing role of natural gas in the global energy market is mainly due to: firstly, the sharp rise in proven gas reserves worldwide and importance and priority given by the major oil importing countries to security and diversification of sources of energy and thus their reduced dependence on oil imports as the single source of energy. Secondly, growing concern for the environment and increasing strenght of environmental pressure groups which has led to definite push by some governments to promote the use of natural gas as the most favored fuel (Omidvar, 2008)

The only disadvantage of natural gas is emissions, particularly those of carbon dioxide and methane. Methane the main component of natural gas has 20 times the greenhouse gas or global warming effect potential of carbon dioxide (Igbatayo and Imuodu, 2009). But a major study performed by the Environmental Protection

Agency and the Gas Research Institute in 1997 concluded that a reduction in emissions from increased natural gas use would strongly outweigh the detrimental effects of increased methane emissions (Speight, 2009). Thus the increased natural gas use in place of other dirtier fossil fuels can serve to lessen GHG emissions and sustain energy security.

Natural Gas can be utilized as Liquefied Natural Gas (LNG), Compressed Natural Gas (CNG), and Gas to Liquids (GTL). CNG is wining more attention and investments in the automobile industry as an alternative to petroleum products, competing with petrol (gasoline) and diesel.due to its lower price in almost all oil importing countries.

3. CNG stands out

Natural gas in the form of CNG is becoming the subject of interest today, as the combustion of gasoline and diesel fuels result in the emission more noxious pollutants (Semin, Idris and Bakar, 2009) and cost more due to high oil prices and high levels of taxation on conventional liquid vehicle fuels..

CNG is often confused with 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 in uncompressed liquid form at very low (cryogenic temperatures). 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 is very cost-competitive when compared with other forms of natural gas, like LNG. Whereas LNG is more suitable for longer range and larger vehicles, CNG is very attractive for smaller vehicles travelling shorter distances and for storing and developing small resource volumes of gas.

3. 1 *Advantages of CNG*

There are good reasons for CNG growth. Five advantages of CNG immediately stand out: 1) emissions; 2) costs; 3) safety record; 4) flexibility; 5) abundant reserves of gas.

Firstly, from the emission point of view, CNG is the most suitable fuel in automobiles. This is in recognition of the favorable emission characteristics of natural gas as the cleanest burning fossil fuel. CNG has almost 40% less CO_2 emission than oil and about 80% less than coal, during combustion (Natural Gas, 2008). (see table 2).

Table 2: Fossil Fuel Emissions

	CO_2	CO	NO	SO	Particulate
Natural Gas	117,000	40	92	1	0.00
Oil	164,000	33	448	1,1222	0.007
Coal	208,000	208	457	2,591	0.016

(Source: Natural Gas and the Environment, http//www.naturalgas.org/environment/naturalgas.asp(accessed May3,2008)

Also an attempt to compare the unregulated emission components of different automobile fuels have demonstrated the efficiency of CNG use as a suitable candidate. The list below shows Emission reduction of CNG when compared to other conventional fuel in automobiles (Natural Gas Vehicles for America, 2011).
Carbon monoxide (CO) by 70%-90%
Non-methane organic gas (NMOG) by 50%-75%
Nitrogen oxides (NOx) by 75%-95%
Carbon dioxide (CO2) by 20%-30%

Second is the economic benefit. As the world continues to experience high costs of gasoline, the low price of CNG is attractive. For instance, is the case where an end-user uses NGV that is powered by CNG for about 50 km daily in the west of America. This end-user is actually able to save more than $600 per year by taking advantage of the 85¢ gallon per gasoline equivalent compared to users running gasoline-fuelled vehicles paying some $4.33 / gallon in 2012 (Electric Auto Shop, 2012). This makes CNG typically, at least, 30% cheaper than gasoline. Apart from CNG being cheaper, it also gives consumers fuel efficiency. Reflecting on the price of gasoline in India, which costs at about 50 Rs/liter (even though being largely government subsidized), in comparison to CNG that sells for only 22 Rs. While expensive petrol gives a standard car owner about 15 km per

liter, the low-cost CNG offers close to 20 km (Electric Auto Shop, 2012).

Profitability/Economics Analysis of CNG compared to its counterparts

The success of any business project is more commonly measured in terms of financial efficiency than any other way. In discussing cash flow, it is common to use a set of profitability "indicators" which takes a quick look at the economic merits of the underlying venture.

Since the use of CNG as a vehicular fuel will require an initial investment to:

- Convert the Engine to run on the compressed gas;
- Pay more for the purchase of new CNG-fuelled vehicles.

It is then considered also as a "Black Box" that absorbs fund and later generates money, in form of extra savings due to the comparative cost advantage of the gas.

Table 3 below shows recent cost per liter of the Premium Motor Spirit (PMS) and Automotive Gas Oil (AGO) as well as prize per M^3 of CNG (with Nigeria in focus). Using the relation and going by the energy content, the following savings (as shown in Table 4) can be obtained, which can then be used to generate a cash flow as follows:

Table 3: Cost of PMS, AGO and CNG in Nigeria

Fuel	Cost (Naira)
Petrol (PMS)	97/liter
Diesel (AGO)	110/liter
CNG	55/M^3

Source: Green Gas Ltd, 2011.

Table 4: Savings from CNG Vehicles

Vehicle Type	Running Cost		Savings By Using CNG		Extra Margins for using CNG
	Petrol	CNG			
Car	N14/KM	N5.5/KM	N8.5/KM	850/Day	N2000/Day
(Mini)Bus	N20/KM	N7.5/KM	N12.5/KM	1250/Day	N3000/Day

Source: Green Gas Ltd, 2011.

Note: Green Gas Ltd is a JV Company of Nigerian Gas Company (NGC) & NIPCO.

The simplest method used to evaluate a project is estimating the time required to recover the costs associated with an alternative. This method is known as the *payback period* or *payout analysis (*Betancourt-Torcat, Ricardez-Sandoval, and Elkamel, 2012). The mathematical model used to estimate the payback period is;

$$\text{Payback period} = \frac{Initial\ Investment}{Annual\ Savings}$$

When cash inflows are uneven, and there is need to calculate the cumulative net cash flow for each period, the following formula below is used (Accounting Explained, 2011):

$$\text{Payback Period} = A + \frac{B}{C}$$

In the above formula,

A = Last period with a negative cumulative cash flow;
B = Absolute value of cumulative cash flow at the end of the period A;
C = Actual Cash Flow during the period after A

Payback period is usually given in time units, usually months or years.

For a Private Car Owner in Nigeria:

Who spent N150000.00 in converting his car to run on CNG, and If he runs 100KM per day, his cash flow (savings) is N850/day. From table 2 savings from a car is N8.5/KM, so for a 100KM per day N850 is saved. Assuming a month is made up of 30 days, and then his savings becomes:

N850 x 30 = N25,500

The table 5 below therefore shows cash flow for a private car owner.

Table 5: Cash Savings (flow) for a private car owner

Months	Cash Flow (N)	Cum. Cash Flow (N)
0	(150,000)	
1	25,500	(124,500)
2	25,500	(99,000)
3	25,500	(73,500)
4	25,500	(48,000)
5	25,500	(22,500)
6	25,500	3,000
7	25,500	28,500
8	25,500	54,000
9	25,500	79,500
10	25,500	105,000
11	25,500	130,500
12	25,500	156,000

From the NCF above the following can be obtained;
Payback period:

Since the cash flow per period are even, the formula to calculate payback period is:

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Cash Inflow per Period}}$$

$$= \frac{150{,}000}{25{,}500}$$

= 5.88 approx. 5.9 months.

Net Cash Recovery (NCR) for 1 year = N156,000
Profit Per Naira Invested within 1 year= 156,000/150,000 = N1.04

Note: Nigerian currency "Naira" is designated as 'N'.

As at the time of this research 1 US Dollar = 155 Naira

Third, is its commendable track record of reliability and safety. This track record spans several decades over the history of vehicles run on CNG. Explosive concerns with CNG used in vehicles have proved to be unfounded.t CNG, is a natural gas under pressure which remains clear, odorless, non-poisonous, and non-corrosive. Nonetheless, robust tanks to withstand gas under pressure and careful positioning of those tanks within vehicles has played a role in their safety record

Fourth, flexibility and ease of use. The basic engine characteristics of a vehicle are retained while converting it to run on CNG. Natural gas gives roughly the same mileage as gasoline. Dedicated natural gas engines are superior in performance to gasoline engines because natural gas has an octane rating of 130 (Quester Gas, 2009). Because natural gas is already in a gaseous state, NGVs have superior starting and drive ability, even under severe hot and cold weather conditions. NGVs experience less knocking and no vapor locking. Some vehicles are also constructed and operated as bi-fuel vehicles with two fuel tanks; one of CNG and one of gasoline or diesel.

Finally, is the abundance of natural gas, as already mentioned above, and the forecast longevity of those resources . and the advantageous geographical location of these giant natural gas reserves serve to guarantee continued and reliable supply of this environmental friendly energy for the global demand over a very long period of time (Omidvar, 2008).

Expanded exploitation of CNG as a substitute for diesel and petrol in automibiles would help significantly to reduce greenhouse-gas emissions levels in developed and developing economies.

Table 6: Global Energy-Related Carbon Dioxide Emissions (Million tons)

			Transition Economies		Developing Countries		World	
	2002	2030	2002	2030	2002	2030	2002	2030
Power Sector	4793	6191	1270	1639	3354	8941	9417	16771
Industry	1723	1949	400	618	1954	3000	4076	5567
Transport	3384	4856	285	531	1245	3353	4914	8739
Residential & Services	1801	1950	378	538	1068	1930	3248	4417
Other*	745	888	111	176	605	1142	1924	2720
Total	12,446	15,833	2444	3501	8226	18,365	23,579	38214

*Includes interantional marine bunkers (for the world's total only)

(Source: IEA, 2004.21 as cited in Igbatayo and Imuodu, 2009)

3.2 Disadvantage of CNG as a Transport Fuel

There are two key disadvantages to CNG in comparison with gasoline and diesel as a vehicle fuel.
(1) *Vehicle luggage space loss*. A CNG cylinder consumes a lot of storage space and has to be placed in the trunk of the car. Also the body of the cylinders too have to be made of good grade steel capable of withstanding the roughs and toughs during travelling. The conversion is another challenge, because of its high cost per vehicle, although this will ultimately be recovered from fuel savings, it will take time to achieve payback.

. (2) Per unit volume there is more than five times the energy in LNG than there is in CNG, making LNG more suitable as a long-distance road vehicle fuel. CNG growth as a road fuel in certain parts of the world (i.e. Asia and South America) remains strong due to the current investments in NGVs and fuel-station infrastructure (Leather, Bahadori, Nwaoha and Wood, 2013). In North America the focus is now more on providing LNG infrastructure for large heavy goods vehicles travelling long distances, in addition to CNG infrastructure for lighter vehicles.

4. The Markets

CNG growth as a transportation fuel is strong.. This is partly due to the current investments in natural gas vehicles. Public CNG refuelling stations are increasing in number worldwide and equipment is now developed and available to allow home fuelling in some regions with grid gas supply.

Worldwide, there were 15.1 million natural gas vehicles and 19, 947 CNG fueling stations as of December 2011, led by Iran with over 2.859 million, Pakistan (2.850 million), Argentina (1.9 million). The table 7 below shows the top 10 countries (NGV Global, 2012).

Table 7 Top 10 countries of NGV population

NGV Population: TOP TEN COUNTRIES		
COUNTRY	**NGV Population**	**% all NGV's in the World**
Iran	2,859,386	18.8
Pakistan	2,850,500	18.8
Argentina	1,900,000	12.5
Brazil	1,694,278	11.2
India	1,100,000	7.2
China	1,000,000	6.6
Italy	779,090	5.1
Ukraine	390,000	2.6
Colombia	348,747	2.3
Thailand	300,581	2.0

(source: NGV Global, 2012).

4.1 In Europe

In Italy the use of CNG vehicles started in the 1930's and has continued off and on until today. Since 2008 there has been a large market expansion for natural gas vehicles caused by the rise of gasoline prices and by the need to reduce air pollution emissions. There are more than 779, 090 NGV and 858 CNG filling stations currently in Italy (NGV Global, 2012).In Germany, CNG-generated vehicles are expected to increase to two million units of motor-transport by the year 2020. And as of December 2011 there are about 96, 215 NGV's and around 903 gas CNG stations in Germany (NGV Global, 2012).

Russia, Ukraine, Spain, Switzerland France and Bulgaria are also investing in the construction of NGV vehicles and CNG filling stations.

4.2 In Asia-Pacific

CNG has grown into one of the major fuel sources used in car engines in Iran, Pakistan, India, China, and Thailand. Asia-Pacific accounts for the most NGV's in the world. Table 8 below shows the average percentage NGV growth since 2002 (NGV Global, 2012).

Table 8. NGV Regional growth for the past 10 years (2002-2012)

NGV REGIONAL GROWTH SINCE 2002 (Ten Years)	
Region	**Average % NGV Growth since 2002**
ASIA-PACIFIC	38.7
EUROPE	16.2
NORTH AMERICA	-1.2
LATIN AMERICA	14.8
AFRICA	16.1
ALL COUNTRIES	**22.9**

(source: NGV Global, 2012).

In Australia more than 35% of Australia's final energy use is employed moving people and goods across the country (Commonwealth of Australia, 2011). As a large continent characterised by major population centres located along the coastline, Australia requires goods to be transported long distances (which is more suited to LNG than CNG). Road transport is the largest user of final energy in the transport sector, accounting for around three-quarters of the sector's fuel consumption (Commonwealth of Australia, 2011), with passenger vehicles accounting for some 61% of the fuel consumed. This is the major reason behind the increase in NGV's population in Australia, together with its abundant supplies of conventional and unconventional gas resources.

4.3 In South and North America

According to Fernandes (2008), CNG vehicles are also commonly used in South America, where these vehicles are mainly used as taxicabs in main cities of Argentina and Brazil, when compared to North America. Argentina, Brazil and Columbia are the three countries with the largest fleets of CNG vehicles with a combined total fleet of more than 3.9 million vehicles by December 2011)? Where is figure 1.

Bolivia, Venezuela and United States of America are other southern and northern American countries with increased use of CNG vehicles of 157426, 105890 and 123000 respectively (NGV Global, 2012).

4.4 In Africa

Egypt ranks as number one in Africa with 157,858 CNG vehicles and 141 fueling stations nationwide (NGV Global, 2012).

With every country in the world trying to phase out toxic emissions, Nigeria could potentially save some N654 billion yearly from the use of compressed natural gas. This figure represents 40 percent of the estimated N1.6 trillion spent by Nigerians on diesel and petrol yearly to run vehicles and industrial machineries (Ebosele, 2008). Currently, Nigeria can boast of 345 NGV's and some 6 refueling station as of December 2011 (NGV Global, 2012).

This number will increase for Nigeria, due to the governments bid to eliminate the problems and shortages associated with vehicle fuel supply.

5. Recommendations

Industry needs to be able to invest with confidence. To do that, it needs secure and reliable access to those resources. If the conditions are right, industry will invest.

And to realise this, we need governments to commit themselves to a more active and pragmatic role. In thinking about these roles, there are a number of specific recommendations that will enhance CNG technologies and investments, they are:

- **Incentives and Tax Breaks**

Of course, enormous demand growth for energy around the world also means that nations must establish policies that allow the energy industry to develop energy from all available and commercially viable resources. History tells us that real change in energy markets can only occur when public policy and private enterprise work hand in hand. This will develop collaborative and innovative solutions to meet the challenge of supplying energy in an environmentally sustainable manner. This can come in form of tax breaks and incentives for both producers and end-users. Producers will only make the investments in gas infrastructure when the economic returns from these investments is favorable (Murtala, Nwaoha, and Olagoke, 2013). By increasing incentives to the gas producers and continuing to develop both international and domestic gas markets where producers can achieve reasonable economic returns on their investments, the issues of under development and investment on CNG will be greatly reduced in a few years. Tax breaks can also be introduced to further encourage huge investment and interests in both NGV importation and CNG refuelling facilities. For instance, Sweden government through its Energy Minister Anna-Karin Hatt has unveiled tax incentives that will increase NGV sales. This will include a reduced tax benefit on company cars running on natural gas for 3 years, from 2014 to end of 2016 (NGV Journal, 2013). It also benefits car buyers 40 percent reduced rate of taxation, which lowers the cost of new NGV's to same level as the petrol and diesel driven vehicles. In turn, leads to more CNG fuelling stations (NGV Journal, 2013).

- **Investment in CNG Infrastructure**

Each day, end-users worldwide use more than 230 million barrels of energy, measured in oil equivalents, from all sources (Glass, 2009). Accordingly, we will need to find and produce more natural gas as well as adequately utilizing it in form of CNG. Globally CNG is getting the much anticipated wide acceptance, and this is due its ability to market small reserves and also monetise offshore reserves which cannot be produced because of unavailable of pipeline or because the LNG option is very costly. This can come in form of investing in small scale CNG projects which provides good opportunity to unlock the market potential by making CNG available to end-users. The simple solution provided by small scale CNG can address individual customer needs in catchment areas. For instance, the Nigerian gas master plan aims to address some of the challenges confronting the Nigeria gas sector, notably that of inadequate infrastructure and commercial framework, which have had a strong impact on the ability of the sector to supply as rapidly as the market opportunity dictates(Egbogah, 2009). Finally, GHG emissions will be greatly reduced through more efficient use of energy, efficiency improvements from operations and investment in CNG facilities. Finally, if the conditions are right, industry will invest (Hayward, 2009).

Putting Tax on Flared Gas

Government should ensure appropriate pricing and tax per cubic meter of gas flared to encourage international oil companies (IOC) and other stakeholders to execute much needed flare-out projects. Such regulation has been introduced in Australia as 'Australian carbon pricing legislation'. In the Australian carbon pricing legislation, a fixed carbon price of $23 a tonne will last for three years (1st July 2012 to 1st July 2015) (Commonwealth of Australia, 2011 cited in Murtala, Nwaoha, and Olagoke, 2013, p.629). It's also to note that small businesses and households will have no direct obligations under the legislation.

6. Conclusion

Leather, Bahadori, Nwaoha and Wood (2013) confirmed that CNG is wining more attention and investments in the automobile industry as an alternative to petroleum products like petrol, diesel, and fuel oil. This is mainly due to its advantage to monetize stranded and small reserves, which accounts for more than one-third of global reserves. In order to effectively utilise CNG, continued investment is very crucial. CNG is greatly utilised in the transportation sector, where it has gained wide acceptance and investment. Its ability to market small reserves is an additional major benefit. The use of NGV's also facilitates energy security and energy diversity.

Although the use of other alternative sources of energy will continue to grow, CNG will together remain the dominant source of energy and will continue to play a key role in the future global energy demand and supply. This is because most of these other alternatives begin from a much smaller resource base than CNG, and the technology, infrastructure and regulatory framework to support them on large scale is expensive and does not currently exist. But surely they will play an important role in the long-run.

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