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Unlocking The Potential Of Compressed Natural Gas (CNG) In Nigeria: A Technical And Market Analysis

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Abstract
This study provides a comprehensive analysis of the potential of Compressed Natural Gas (CNG) as a viable energy alternative in Nigeria, focusing on its technical and market feasibility. Nigeria, with substantial natural gas reserves, has yet to fully exploit CNG for transportation and cooking due to infrastructure limitations, high conversion costs, and low public awareness. The analysis compares the advantages of CNG over other fuels, such as Liquefied Petroleum Gas (LPG) and diesel, highlighting its higher combustion efficiency, lower emissions, and suitability for high-compression engines. The study identifies key challenges, including infrastructure deficits and safety concerns, and proposes solutions to mitigate these barriers. The potential market for CNG in transportation and cooking sectors in Nigeria is vast, with significant cost savings and environmental benefits. Strategic initiatives, including government incentives, public awareness campaigns, and infrastructure development, are critical to unlocking the potential of CNG, positioning it as a cornerstone of sustainable energy future in Nigeria.
Keywords: *Compressed Natural Gas (CNG), Nigeria, energy alternative, market analysis, infrastructure, combustion efficiency, transportation, cooking, environmental impact, safety concerns.*

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I. Introduction

Nigeria relies on various types of fuels for cooking and transportation, each with its distinct advantages and drawbacks. The primary fuels used include petrol, diesel, kerosene, Liquefied Petroleum Gas (LPG), and Compressed Natural Gas (CNG). These fuels cater to different energy needs and economic conditions across the country[1, 2]. With a growing population and expanding industrial activities, the energy demand in Nigeria is significantly increasing[2], necessitating a diversified and efficient fuel mix to ensure sustainability and economic growth. Among these options, CNG presents a compelling case for broader adoption due to its environmental benefits and potential for enhancing energy security. This option is currently under explored in Nigeria, leading to an extensive planning in ensuring it is efficient roll out. The physiochemical properties of LPG, CNG and kerosene are shown in Table 1.

Table 1: Physiochemical Properties of LPG, CNG and Kerosene [3].

Property	LPG	CNG	Kerosene
Primary Components	Propane, Butane	Methane	Various hydrocarbons
Storage State	Liquid	Gas	Liquid
Storage Pressure	Low (approx. 5-15 bar)	High (200-248 bar)	Low
Heat Value (MJ/kg)	46 - 51	47.5	43.1
Octane Number	110	120-130	-
Auto-ignition Temperature (°C)	450	540	220
Flammability Limits in Air (vol%)	2.2-9.5	4.3-15.2	0.6-4.0
Common Uses	Cooking, Heating, Vehicles	Vehicles, Industrial	Cooking, Heating, Jet fuel

CNG and LPG both serve as alternative fuels with distinct properties and applications. CNG is more suited for high-compression engines due to its high octane number, which allows for efficient combustion and better engine performance[4]. This makes CNG an ideal choice for vehicles, particularly in urban areas where emissions regulations are stringent. The high octane number of CNG not only enhances engine efficiency but also reduces the risk of engine knocking, thereby extending the lifespan of the engine and reducing maintenance costs[5, 6].

On the other hand, LPG, with its high energy content and lower storage pressure, is particularly well-suited for portable and domestic uses. Its ability to be stored as a liquid under moderate pressure makes it easy to

transport and store in various container sizes, ranging from small cylinders for household cooking to larger tanks for industrial heating applications[7]. The versatility and convenience of LPG have made it a popular choice for cooking, heating, and even as fuel for some vehicles, particularly in areas where the infrastructure for CNG is not yet developed[8, 9].

While both CNG and LPG provide cleaner alternatives to traditional petroleum-based fuels, their applications are driven by their distinct physical and chemical properties **(**

Table 1). The lower carbon emissions and suitability of CNG for high-compression engines position it as a strategic fuel for reducing urban air pollution and enhancing energy security in the transportation sector that is currently facing significant challenges in the country[1]. Conversely, the portability and high energy content of LPG make it an excellent option for residential and commercial energy needs, offering a practical solution for areas that often rely on the use of firewood[10].

In Nigeria, leveraging the complementary strengths of CNG and LPG can lead to a more robust and resilient energy landscape. By promoting the use of CNG in transportation and industrial sectors, while encouraging LPG adoption in households and small businesses, Nigeria can optimise its energy resources, reduce environmental impacts, and improve energy access across the country[1, 11].

Combustion efficiency is a critical factor when comparing different fuels. CNG exhibits high combustion efficiency due to its high octane number (120-130) and low carbon content. This results in cleaner combustion with fewer emissions of pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), and particulate matter (PM) [5, 12].

In contrast, firewood, which is commonly used for cooking in rural Nigeria, has a much lower combustion efficiency. Burning firewood releases significant amounts of CO_2, CO, and PM, contributing to indoor air pollution and respiratory health issues. Additionally, the use of firewood leads to deforestation, exacerbating environmental degradation[13, 14].

Liquid fuels such as gasoline and diesel have moderate to high combustion efficiencies but produce higher levels of NO_x and PM compared to CNG[15]. Diesel, in particular, has a high energy content and efficiency, but its combustion results in the emission of significant quantities of NO_x and PM, making it less environmentally friendly than CNG[16].

Table 2 shows the comparison of the combustion efficiency of different fuels widely used in Nigeria[17].

Table 2: Comparison of Combustion Efficiency of different fuels.

Fuel Type	Combustion Efficiency	Emissions (CO, NO_x, PM)	Environmental Impact
CNG	High	Low	Low
LPG	High	Low	Low
Gasoline	Moderate	Moderate	Moderate
Diesel	High	High	High
Kerosene	Moderate	High	High
Firewood	Low	High	High

II. Market Potential And Gaps In Nigeria

The market for CNG in Nigeria presents significant opportunities alongside notable gaps that must be addressed to realise its full potential. Despite the substantial natural gas reserves in Nigeria, estimated at over 200 trillion cubic feet, the transition to CNG has been slow due to infrastructure limitations, high initial conversion costs, and low public awareness.

Infrastructure Limitations

One of the major hindrances to the wide-spread adoption of CNG powered road transportation in Nigeria is the present state of infrastructure for natural gas. Nationally, Nigeria ranks low in CNG refuelling stations, tight storage facilities, and related pressures needed for a seamless distribution of CNG[1]. Due to this condition, Nigeria has only a few refuelling stations in operation, mostly situated within Abuja, Lagos and Benin commissioned by NNPCL and NIPCO. However, it was discovered that there is a high market demand for CNG among fleet operators as an alternative to premium and diesel[18]. To tap into this market, CNG refuelling facility in Nigeria needs to undergo proper needs assessment, planning, and forecast to cater to further needs[19].

In recent years, the Federal Government of Nigeria implemented measures aimed at capitalising and developing the vast natural gas resources of the nation. However, several hindrances including regulatory measures, policy and strategy framework, and technical limitations needed to be amended for the successful delivery of all facets of tapping into CNG powered road transportation. There are a few assessments regarding CNG vehicles in Nigeria, which is a large gap[2, 19, 20].

High Initial Conversion Costs

The initial cost of converting vehicles to CNG is another significant barrier. For example, according to study by NIPCO, the cost of converting a petrol or diesel vehicle to CNG costs between NGN 200,000 and NGN 300,000 in 2017, equivalent to over NGN 570,000 in 2024. While the long-term savings from lower fuel costs and reduced maintenance expenses can offset these initial costs[21], the financial burden remains a deterrent for many potential users. Financing solutions, such as those proposed by the Sustainable Energy Access Projects (SEAP) initiative in partnership with several banks, can help mitigate this challenge by providing loans and subsidies to facilitate conversions. Moreover, government incentives and subsidies could further lower the financial entry barrier, making CNG a more attractive option for a broader range of consumers.

Public Awareness and Acceptance

The promotion and acceptance of CNG as a fuel choice in Nigeria are essential for the establishment, operation, and enduring success of CNG facilities. Awareness encompasses the perceptions, knowledge, attitude, and understanding of consumers, businesses, and other stakeholders. Research shows that public awareness levels about alternative transport fuels vary widely in different countries[19, 22]. Acceptance of CNG as a fuel choice could enhance CNG program development and implementation efforts in Nigeria. A gap between acceptance and awareness is expected, which could be addressed through education and awareness campaigns. Effective communication and education campaigns are needed to build consumer confidence and encourage the transition to CNG. Demonstration projects and pilot programs can also play a crucial role in showcasing the practicality and advantages of CNG.

III. Business Potential And Environmental Impact Of A CNG

Setting up a CNG plant in a pipeline region offers a significant advantage in terms of accessing the necessary natural gas supply. However, Nigeria faces challenges with gas pipeline infrastructure[23], which hinders the growth of the CNG sector. Virtual pipeline distribution models, which use trucks[24] to transport CNG, are presented as a solution to bypass the need for extensive pipeline construction. This approach can be particularly beneficial in regions with existing pipeline infrastructure but lacking last-mile connectivity.

The Presidential CNG Initiative aims to rapidly expand CNG infrastructure, with plans to establish numerous CNG stations across the country, thereby making it accessible to a broader population. For example, collaboration of NNPC with NIPCO Gas Ltd. aims to set up 35 CNG stations by 2025, potentially serving over 200,000 vehicles daily[25]. This initiative not only reduces fuel costs but also supports energy security by leveraging abundant natural gas reserves in Nigeria.

The prospects for CNG in Nigeria are increasingly promising, especially in the transportation and cooking sectors, given the current economic and environmental landscape.

Transportation sector

The transportation sector presents a significant opportunity for CNG adoption, driven by the potential cost savings for consumers and revenue generation for investors. Compared to petrol and diesel, CNG offers substantial cost benefits. As of recent estimates, the price of CNG per litre equivalent is approximately NGN 250 per litre[26], compared to NGN 769.62 per litre for petrol and NGN 1403.96 per litre for diesel[27]. This price differential translates into significant savings for vehicle operators. At these prices, let's consider for example, a commercial bus operator who typically consumes about 50 litres of petrol per day could save up to NGN 26,000 daily by switching to CNG, amounting to annual savings of over NGN 9 million.

For investors, the revenue potential is equally promising. Given that Nigeria has over 12 million registered vehicles[27], with a significant portion used for commercial transportation, the potential market for CNG is vast. If just 10% of these vehicles were to convert to CNG, the demand could reach over 1.2 billion litres equivalent per year. Assuming a profit margin of NGN 30 per litre, investors could generate annual revenues exceeding NGN 36 billion from the transportation sector alone.

Cooking sector

In the cooking sector, CNG provides a cost-effective alternative to both biomass and Liquefied Petroleum Gas (LPG). The current cost of LPG in Nigeria is approximately NGN 1483.69 per kilogram[27], whereas CNG, when measured in energy equivalence, could cost as low as NGN 230 per kilogram. For a typical household consuming 15 kg of LPG per month, switching to CNG could result in monthly savings of around NGN 18,800, or NGN 225,600 annually.

The potential market size in the cooking sector is substantial, with over 40 million households in Nigeria. If 5% of these households adopt CNG as their primary cooking fuel, the demand could reach 300 million

kilograms annually. Investors entering this market could see significant returns, particularly if they target urban centres where the infrastructure for CNG distribution is more feasible.

Environmental impact of CNG

The environmental benefits of CNG are one of the most compelling arguments for its adoption. CNG burns much cleaner than petrol, diesel, or biomass, producing fewer harmful emissions such as carbon monoxide, nitrogen oxides, and particulate matter[28]. In the transportation sector, vehicles running on CNG emit up to 31.5% less carbon dioxide compared to those running on petrol [29], significantly reducing the carbon footprint of the transport industry. This reduction in emissions is crucial for Nigeria, which faces increasing pressure to meet global climate commitments and improve air quality in its major cities.

In the cooking sector, the shift from biomass to CNG can have profound environmental and health impacts. Currently, the widespread use of firewood and charcoal contributes to deforestation and indoor air pollution[30], leading to respiratory issues among millions of Nigerians. By replacing biomass with CNG, these adverse effects can be mitigated, contributing to the preservation of forests and the improvement of public health. Moreover, the reduction in deforestation can have positive downstream effects, such as preserving biodiversity and reducing soil erosion.

IV. Safety Concerns And Engineering Controls For CNG

While CNG offers significant business potential and cost savings in Nigeria, there are notable disadvantages, particularly around safety concerns. As with any fuel, the handling, storage, and usage of CNG must adhere to stringent safety protocols to mitigate risks. Understanding these disadvantages and implementing appropriate engineering controls is crucial for ensuring the safe adoption of CNG. Additionally, comparing the safety risks of CNG with other commonly used fuels such as gasoline, diesel, kerosene, and LPG highlights the unique challenges and safety considerations associated with each fuel type.

Table **3** outlines key risk indicators associated with various fuels used in Nigeria, highlighting potential safety concerns and the importance of proper engineering controls.

Table 3: Risk indicators associated with various fuels used in Nigeria.

Fuel Type	Risk Indicator	Description
CNG	High Storage Pressure	Stored at 200-248 bar, posing explosion risks if tank integrity is compromised.
	Fuel Tank Integrity	Requires robust, impact-resistant tanks to prevent leaks.
	Fire Hazard	Flammable gas that can ignite if leaked and exposed to an ignition source.
	Public Perception and Training	Lack of awareness and training on safe handling increases risk of accidents.
LPG	Leakage	Stored under pressure; leaks can cause fires or explosions.
	Explosion Risk	Highly flammable, posing significant explosion risk if containment fails.
	Handling and Storage	Requires careful handling and proper storage to avoid accidents.
Gasoline	Flammability	Highly flammable liquid, posing fire hazards.
	Volatility	Easily vaporizes, increasing risk of explosive mixtures.
	Spillage and Contamination	Spills can cause environmental contamination and fire risks.
Diesel	Flammability	Less flammable than gasoline but still poses fire risks.
	High Energy Density	High energy content can lead to intense fires.
	Spillage	Spills can cause environmental harm and fire risks.
Kerosene	Combustion Products	Produces smoke and soot, contributing to indoor air pollution and respiratory issues.
	Flammability	Flammable, posing fire hazards if not handled properly.
	Storage and Handling	Requires proper storage to prevent leaks and accidental fires.

Firewood	Smoke and Soot	Burning releases significant smoke and particulates, harmful to health and environment.
	Deforestation	Extensive use contributes to deforestation and environmental degradation.
	Inefficient Combustion	Low combustion efficiency leads to higher fuel consumption and more emissions.

The safe handling of CNG requires rigorous safety measures and controls due to the inherent risks associated with high storage pressures, material integrity, and potential fire hazards. Given that CNG is stored at extremely high pressures, typically between 200 and 248 bar[31, 32], ensuring the integrity of storage tanks and refuelling infrastructure is paramount. Any breach in these systems could lead to dangerous leaks or explosions. To mitigate these risks, it is essential to use high-quality storage tanks constructed from robust materials like steel or advanced composites, capable of withstanding these intense pressures[3]. These tanks must also be equipped with high-pressure safety valves that automatically release excess pressure in a controlled manner, preventing over-pressurisation and potential explosions[33].

Material integrity is another critical aspect of CNG safety. The storage tanks must be resistant to damage from impacts, corrosion, and other forms of degradation, as a compromised tank could lead to the high-pressure release of gas, posing serious safety risks[34]. Regular inspections and maintenance are crucial to ensure the ongoing safety of these tanks. This includes monitoring for signs of wear and corrosion and ensuring that all safety valves and pressure relief devices are functioning correctly. Moreover, the design and construction of refuelling stations must prioritize safety, incorporating certified components for pumps, hoses, and connectors, as well as safety barriers and clear signage to guide users.

Despite being less flammable than gasoline or diesel, CNG remains a combustible gas, and leaks could ignite if exposed to an ignition source. To reduce this risk, advanced leak detection systems should be installed within storage and refuelling infrastructure. These systems can include gas detectors that trigger alarms and automatic shutoff valves in the event of a leak[35]. Additionally, ensuring that refuelling stations and storage areas are well-ventilated is essential, as proper ventilation dissipates any leaked gas, reducing the risk of accumulation and potential ignition.

Public perception and training are also crucial components of CNG safety. There is often a lack of awareness about the risks associated with CNG and the correct procedures for its handling. Misunderstandings or mishandling can lead to accidents, making public awareness campaigns and training programs essential. These initiatives should educate users on how to recognise leaks, follow proper refuelling procedures, and respond appropriately in emergencies.

Finally, comprehensive emergency response plans must be developed and implemented to manage any incidents involving CNG effectively. These plans should include protocols for addressing CNG leaks or fires, and all personnel, including first responders, should be trained on these protocols. Regular drills and updates to the response plans will ensure preparedness and a swift, effective response to any emergencies.

By implementing these engineering controls and safety measures, the potential risks associated with CNG can be significantly mitigated, making it a safer and more viable alternative fuel for Nigeria's transportation and domestic use.

V. Conclusion

The potential of CNG as a sustainable energy alternative in Nigeria is significant, particularly in the transportation and domestic sectors. Despite the challenges of infrastructure limitations, high conversion costs, and low public awareness, strategic investments in infrastructure development, government incentives, and public education can unlock the benefits of CNG. By addressing these barriers, Nigeria can enhance energy security, reduce environmental impacts, and create economic opportunities, positioning CNG as a key component of the energy landscape of the country.

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