

PAPER 21 - REVIEWING THE SAFETY, BENEFITS, AND IMPLEMENTATION OF CNG AND CBG ADOPTION AS ENERGY AND TRANSPORT FUELS IN NIGERIA

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ABSTRACT

The removal of fuel subsidies in Nigeria highlights inefficiencies in the country's energy mix, resulting in a significant increase in energy and transportation costs. This has led to higher prices for goods and services across the board, worsening the country's economic situation. Consequently, the adoption of alternative fuel sources such as Compressed Natural Gas (CNG) and Compressed Biomethane Gas (CBG) becomes imperative. This review article explores the safety considerations, economic benefits, and energy security implications associated with replacing traditional fossil fuels like petrol and diesel with CNG and CBG in both the energy and transportation sectors. It offers a comprehensive analysis of the advantages, potential challenges, and the current state of adoption of CNG/CBG in Nigeria and other parts of the world, underscoring the urgency and importance of embracing these alternative fuel options. Drawing from a diverse range of academic and scientific sources, this review provides a thorough and robust examination of this critical subject and its implementation.

KEYWORDS: Compressed Natural Gas (CNG), Compressed Biomethane Gas (CBG), Energy Security, Energy Sustainability, Clean Environment, Nigeria

1. INTRODUCTION

The utilization of Compressed Natural Gas (CNG) and Compressed Biomethane Gas (CBG) as alternative fuels in the energy and transportation sectors has garnered significant attention due to their potential availability, affordability, emissions reduction, and enhanced fuel efficiency. Both CNG and CBG represent gaseous forms of natural gas compressed for use in internal combustion engines (Kaushik, *et al.*, 2022), offering substantial benefits over traditional gasoline and diesel fuel (Okoro *et al.*, 2024).

CNG, akin to gasoline, is sourced from underground reserves and primarily consists of compressed methane gas, typically extracted from natural gas wells or obtained as a byproduct of oil extraction (Dam *et al.*, 2022). It is mainly composed of methane with trace amounts of other gases such as ethane, propane, and butane. Production involves compressing natural gas to pressures ranging from 200 to 250 bars to reduce its volume for storage and transportation. Commonly employed in vehicles like buses, trucks, and cars, CNG is celebrated for its reduced carbon content and lower emissions of pollutants like nitrogen oxides and particulate matter, making it an environmentally favorable alternative (Trivedi *et al.*, 2020).

In contrast, CBG is derived from organic materials like agricultural waste, food waste, sewage, or landfill gas through anaerobic digestion or biomethanation processes. This involves breaking down organic matter by bacteria in the absence of oxygen to produce biogas, which is then purified and compressed to form CBG. This renewable fuel not only offers a sustainable alternative to fossil fuels but also aids in mitigating greenhouse gas emissions by utilizing organic waste that would otherwise release methane into the atmosphere (Lucas *et al.*, 2023).

Both CNG and CBG are methane-based gases that can be interchangeably used with diesel or petrol engines upon conversion. While both offer clean-burning properties and a reduction in particulate matter emissions, they differ in their sources and production processes, with CNG primarily derived from natural gas wells and CBG produced from organic waste through anaerobic digestion and purification (Miroslaw *et al.*, 2023).

Extensive research has underscored the advantages of CNG and CBG, including their potential to enhance fuel consumption, reduce exhaust emissions, and improve energy security. Moreover, advancements in storage technology have further bolstered their application as transport fuels, showcasing their viability as sustainable and cost-effective alternatives to traditional fuels. The versatility of CNG and CBG in various engine types, including dual-fuel compression-ignition engines, and their feasibility for marine transportation further emphasizes their potential role in mitigating environmental impact and addressing energy needs (Jamrozik *et al.*, 2019; Ibeneme & Ighalo, 2020).

2. THE CHEMICAL COMPOSITION OF COMPRESSED NATURAL GAS (CNG) AND COMPRESSED BIOMETHANE GAS (CBG)

The chemical composition of Compressed Natural Gas (CNG) and Compressed Biomethane Gas (CBG) is a subject of significant interest due to their diverse applications across various sectors. While both gases share similarities in their major gaseous compounds, the production processes for biomethane involve additional steps such as methane content upgrading and cleaning to eliminate various impurities, distinguishing it from natural gas (Abanades *et al.*, 2021; Tonrangklang *et al.*, 2021).

Biomethane, chemically identical to methane, holds promise as a renewable resource for vehicle fuel or injection into natural gas grids, offering potential to replace fossil fuel natural gas and contributing to sustainable energy transitions (Kabeyi & Olanrewaju, 2022). It can also be utilized as compressed biomethane gas for vehicle and engine fuel, and distributed through natural gas or local biogas grids (Tanat *et al.*, 2021).

In terms of production, biomethane is often incentivized in European countries for grid injection or as a biofuel for vehicles, with processes including anaerobic digestion, methanation, and upgrading to ensure high methane content (Caposciutti *et al.*, 2020). Its chemical potential enables direct use as a vehicle fuel or conversion into electricity and heat in cogeneration units, emphasizing its versatility and sustainability (Kamalimeera & Kirubakaran, 2021). Regarding purification processes, both CNG and CBG undergo various methods to remove impurities and meet quality standards for compression and transportation. Membrane technology and adsorption processes are commonly employed for natural gas purification, with advancements such as Metal-Organic Frameworks (MOFs) showing promise in enhancing purification efficiency (Imtiaz *et al.*, 2022; Tan *et al.*, 2022). Additionally, optimization of purification processes is essential to reduce energy consumption and ensure gas quality meets required standards (Shi *et al.*, 2020). For biogas purification, several techniques are utilized, including chemical absorption, adsorption, and biological removal of impurities, aimed at enhancing biogas composition and quality for various applications (Nevzorova & Karakaya, 2020). Innovative approaches such as enzymatic pretreatment and thermal techniques have shown potential in improving biogas production and quality (Nevzorova & Karakaya, 2020). The purification of both natural gas and biogas involves a range of techniques and processes aimed at removing impurities, enhancing gas quality, and maximizing yield, contributing to sustainable energy applications and environmental conservation efforts.

3. SAFETY AND BENEFITS OF ADOPTION OF CNG AND CBG AS ENERGY AND TRANSPORT FUEL

3.1 ENVIRONMENTAL IMPACT ASSESSMENT

Decreased Greenhouse Gas Emissions: Both CNG and CBG are acknowledged for their low carbon content, positioning them as cleaner alternatives to traditional fossil fuels. Research conducted by Trivedi *et al.*, (2020) revealed that CNG vehicles emit substantially fewer greenhouse gases (GHGs) compared to their gasoline or diesel counterparts. This finding has spurred the adoption of CNG/CBG as a means to address air pollution and combat climate change.

3.2 ENHANCED AIR QUALITY

Incorporating CNG/CBG in engines and vehicles leads to diminished particulate matter emissions, decreased nitrogen oxide (NO_x) emissions, and reduced volatile organic compounds. This decrease in air pollutants significantly benefits local air quality, particularly in urban regions. Research conducted by Tong *et al.* (2020) showcased the enhancements in air quality attributed to CNG/CBG vehicles and combustion engines.

3.3 ENHANCING ENERGY SECURITY

Minimized Reliance on Imported Oil: Numerous nations, such as Nigeria, rely heavily on imported oil to fulfill their energy and transportation requirements, rendering them susceptible to global oil price fluctuations and supply interruptions. Transitioning to domestically sourced natural gas (CNG) or biomass (CBG) for transportation fuel and electricity generation can break this dependency on refined crude oil, thereby bolstering energy security. Research conducted by Rotman *et al.* (2019) highlights the geopolitical benefits of reducing crude oil dependence, leading to a bolstered national economy.

3.4 ECONOMIC CONSIDERATIONS

Financial Benefits: Natural gas (CNG) and biomass (CBG) are readily accessible and generally cheaper than gasoline or diesel when compared on an energy-equivalent basis (Drielli *et al.*, 2023). This economic advantage,

combined with governmental incentives and tax benefits for CNG/CBG engines and vehicles, has the potential to result in substantial savings for both consumers and fleet operators. A study conducted by the U.S. Department of Energy (DOE) details the cost-effectiveness of CNG (Kagiri, 2019).

3.5 DOMESTIC NATURAL GAS RESERVES AND ORGANIC WASTE

In nations endowed with ample natural gas reservoirs and significant organic waste resources, such as Nigeria, adopting CNG/CBG for transportation and electricity offers an opportunity to capitalize on domestic energy reservoirs. The report by Nwogu *et al.* (2020) underlines the economic advantages of utilizing domestic natural gas and organic waste. The prospect of oil serving as a sustainable long-term source of foreign exchange appears increasingly dim. Consequently, the Nigerian government must prioritize the development and integration of CNG and CBG technologies with other renewable energy.

4. CHALLENGES AND BARRIERS TO CNG AND CBG ADOPTION

4.1 INFRASTRUCTURE DEVELOPMENT

4.1.1 AVAILABILITY OF DISPENSING STATIONS

A notable hurdle hindering the widespread acceptance of CNG and CBG as energy and automotive fuels is the scarcity of CNG/CBG dispensing stations (Nouni *et al.*, 2021). Building a dependable network of CNG/CBG refueling stations is pivotal to assist owners of CNG/CBG engines/vehicles (Mustafi & Agarwal, 2020). The growth of CNG/CBG infrastructure differs across regions and is frequently shaped by governmental regulations and incentives. Guaranteeing a sufficient quantity of conveniently located CNG stations is vital in overcoming this obstacle (Philipp *et al.*, 2020).

4.1.2 PIPELINE INFRASTRUCTURE

CNG distribution often relies on pipelines to transport natural gas from production facilities to refueling stations (Hryhoriy *et al.*, 2021). The availability and capacity of these pipelines are vital considerations for the growth of the CNG market. The development and maintenance of an efficient pipeline infrastructure are essential to ensure a consistent and reliable supply of CNG to dispensing stations (Igbojionu, *et al.*, 2019).

4.2 ENGINE RANGE AND REFUELING TIME

4.2.1 LIMITATIONS OF CNG/CBG VEHICLES

CNG/CBG engine/vehicles may have limitations in terms of their driving range compared to traditional gasoline or diesel engines/vehicles. This is due to the need for larger CNG/CBG storage tanks to achieve an adequate range. For some applications, such as long-haul trucking, this limitation may be a barrier to adoption. Manufacturers and researchers are continually working on improving CNG/CBG engine or vehicle efficiency to extend their range (Dahlgren, 2022).

4.2.2 TECHNOLOGICAL ADVANCES

Overcoming the limitations of CNG/CBG engines often requires technological advancements in storage tank design, engine efficiency, and fueling infrastructure (Suroto *et al.*, 2020). Research and development in these areas are ongoing to enhance the range and reduce refueling times. Innovations such as lightweight composite CNG/CBG tanks and faster refueling methods have the potential to address these challenges.

4.3 AWARENESS CAMPAIGNS

Awareness campaigns play a significant role in overcoming barriers related to public perception. These campaigns can provide information about the safety, environmental, and economic benefits of CNG/CBG, dispelling myths and misconceptions. Government agencies, environmental organizations, and industry stakeholders often collaborate on campaigns to promote CNG/CBG as a viable and safe alternative energy fuel.

5. CASE STUDIES OF COUNTRIES THAT HAVE ADOPTED CNG AND CBG AS ENERGY AND TRANSPORT FUEL

5.1 EXPERIENCES FROM COUNTRIES LEADING IN CNG/CBG ADOPTION

5.1.1 INDIA

India stands out as a notable example of successful adoption of CNG/CBG in the energy and transport sector. Recognizing the environmental and economic advantages of CNG/CBG, the Indian government has implemented policies and regulations to promote its usage (Tapas *et al.*, 2020). Major cities like Delhi, Mumbai, and Ahmedabad have established extensive networks of CNG/CBG refueling stations to cater to both public and private transportation and domestic needs (Suverna *et al.*, 2020). Delhi, in particular, boasts one of the world's largest CNG/CBG bus fleets. This transition has not only resulted in reduced emissions but has also enhanced air quality in these urban areas (Trivedi, *et al.*, 2020). India's experience underscores the potential for widespread adoption of CNG/CBG on a large scale, especially when bolstered by governmental initiatives and infrastructure development.

5.1.2 PAKISTAN

Pakistan has made notable advancements in utilizing CNG/CBG as a transportation fuel (Muhammad *et al.*, 2022). The nation confronted substantial energy and environmental obstacles, with air pollution emerging as a significant issue. In response, Pakistan directed investments towards CNG/CBG infrastructure and encouraged the conversion of gasoline and diesel vehicles to CNG/CBG (Rafiq *et al.*, 2022). This initiative markedly decreased dependence on conventional fossil fuels and mitigated greenhouse gas emissions. The success of CNG in Pakistan serves as a model demonstrating how the adoption of alternative fuels can effectively tackle environmental concerns and enhance energy security in developing countries (Muhammad *et al.*, 2022).

5.1.3 ARGENTINA

Argentina has enthusiastically embraced CNG/CBG for both public and private transportation ((Nikas, *et al.*, 2022). The Argentine government has introduced incentives to promote CNG/CBG usage, leading to a significant rise in the number of CNG-fueled vehicles on the streets ((Nikas, *et al.*, 2022). The integration of CNG has not only diminished the carbon footprint but has also provided financial savings to consumers owing to the lower cost of CNG/CBG compared to gasoline (Grassi *et al.*, 2021)). Argentina's experience highlights the economic and environmental advantages of shifting towards CNG/CBG.

6. IMPLEMENTATION OF CNG AND CBG AS ENERGY FUEL

Implementing CNG and CBG as alternative energy fuels involves several key steps and considerations. The following implementation strategies are proposed to expand, encourage, and enhance the adoption of CNG and CBG as alternative energy fuels in Nigeria.

6.1 POLICY SUPPORT AND REGULATORY FRAMEWORK

It is essential for governments to formulate supportive policies and regulatory frameworks to encourage the adoption of CNG and CBG as energy fuels (Sirothiya & Chavadi, 2020). For instance, in India, the government has implemented initiatives such as the Pradhan Mantri Ujjwala Yojana to promote clean cooking fuel, including CBG and CNG (Breitenmoser *et al.*, 2019).

6.2 INFRASTRUCTURE DEVELOPMENT

Creating a sturdy infrastructure for distributing CNG and CBG is essential, encompassing the establishment of refueling stations and transportation pipelines (Takman & Andersson-Sköld, 2021). Investments in infrastructure development are vital to guarantee accessibility and convenience for consumers (Akther, 2023).

6.3 TECHNOLOGICAL DEVELOPMENT AND INNOVATION

Continuous research and development play a pivotal role in enhancing the efficiency of CNG and CBG production, storage, and utilization technologies (Sawale & Kulkarni, 2022). Nigerian universities, particularly federal universities, could be instrumental in this aspect, focusing on research and development of Compressed Natural Gas (CNG) and Compressed Biomethane Gas (CBG) in various forms. Each Nigerian university should establish a center for the conversion of petrol and diesel engines/vehicles to CNG/CBG engines/vehicles. These centers should be mandatory for acquiring skills, where students learn about CNG/CBG, their applications, and the conversion of petrol and diesel engines to CNG/CBG engines. The government must ensure that conversion kits are affordable and readily available. This initiative will create numerous job opportunities for Nigerians and foster a heightened interest in energy security and sustainability. Furthermore, innovation in gas compression and purification technologies has the potential to improve the feasibility and scalability of CNG and CBG as energy fuels (Jagtap & Dalvi, 2021).

6.4 FINANCIAL INCENTIVES AND SUBSIDIES

To stimulate investment in CNG and CBG infrastructure and vehicles, governments may offer financial incentives and subsidies (Schipfer, *et al.*, 2022). Subsidizing equipment such as biogas plants and CNG conversion kits can incentivize consumers to adopt these fuels (Patterson *et al.*, 2011).

6.5 AWARENESS AND EDUCATION

Public awareness campaigns emphasizing the environmental and economic advantages of CNG and CBG can foster consumer acceptance (Sawale *et al.*, 2020). Educational initiatives targeting vehicle manufacturers, fleet operators, and consumers can enhance comprehension and acceptance of CNG and CBG technologies.

6.6 COLLABORATION AND PARTNERSHIPS

Collaboration among government agencies, private sector stakeholders, and research institutions is vital for the effective execution of CNG and CBG adoption efforts (Bhatia *et al.*, 2020). Public-private partnerships can expedite the deployment of CNG and CBG infrastructure and facilitate technology transfer and knowledge exchange. By implementing these measures, policymakers and industry stakeholders can promote the widespread adoption of CNG and CBG as sustainable energy fuels, thereby reducing greenhouse gas emissions and bolstering energy security.

7. CONCLUSION

The adoption of Compressed Natural Gas (CNG) and Compressed Biomethane Gas (CBG) in engines and automotive applications presents numerous environmental benefits, including reduced greenhouse gas emissions, lower levels of particulate and NO_x emissions, and quieter engine operation. These benefits contribute to improved air quality and noise pollution reduction in urban areas. With its environmental advantages and widespread availability, CNG/CBG emerges as a promising alternative fuel option for a more sustainable and healthier energy and transportation future. Furthermore, the growing interest in CNG/CBG as an energy fuel is stimulated by its multifaceted advantages, including environmental sustainability, enhanced energy security, and economic viability. These factors collectively underscore the importance of considering CNG/CBG as a practical and sustainable solution in the transportation and energy sectors. By embracing CNG and CBG technologies, Nigeria has the potential to shield the country from global crude oil crises by accelerating its transition towards a more sustainable and resilient energy future while fostering economic development and improving public health.

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