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ADOPTION OF COMPRESSED NATURAL GAS (CNG) AND COMPRESSED BIOMETHANE GAS (CBG) AS ENERGY AND TRANSPORT FUELS IN NIGERIA: A REVIEW OF SAFETY, BENEFITS, AND IMPLEMENTATION STRATEGIES**Muhibbu-Din Eniola Ismail**

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ABSTRACT

The removal of fuel subsidies in Nigeria has heightened energy and transportation costs, intensifying inflationary pressures and economic instability. To address this, adopting alternative fuels particularly Compressed Natural Gas (CNG) and Compressed Biomethane Gas (CBG) offers a pathway toward energy diversification and resilience. This review systematically synthesizes academic and technical literature, including 45 studies published between 2010 and 2024, to assess the safety, environmental, economic, and energy security implications of transitioning from petroleum fuels to CNG and CBG. Findings reveal that while CBG provides superior environmental benefits and long-term sustainability, CNG remains more cost-effective for short-term implementation. The study identifies policy, infrastructure, and technological gaps limiting adoption and concludes with targeted recommendations to guide Nigeria's sustainable energy transition strategy.

Keywords: Compressed Natural Gas (CNG); Compressed Biomethane Gas (CBG); Energy Security; Environmental Sustainability; Alternative Fuels; Transportation.

1. INTRODUCTION

The adoption of Compressed Natural Gas (CNG) and Compressed Biomethane Gas (CBG) as alternative energy carriers in the energy and transportation sectors has garnered increasing scholarly and industrial interest globally, driven by their potential for improved fuel availability, cost-effectiveness, enhanced energy efficiency, and significant reductions in pollutant emissions (1-2). Both CNG and CBG are compressed gaseous fuels utilized in internal combustion engines, offering distinct environmental and performance advantages compared to conventional gasoline and diesel fuels. CNG, primarily composed of methane with minor fractions of other hydrocarbons (3), is typically sourced from subterranean natural gas reserves or as a byproduct of petroleum extraction, requiring compression to high pressures (200-250 bar) for efficient storage and transportation. Its application spans various vehicular modes, including public buses, freight trucks, and private automobiles, and is valued for its lower carbon intensity and reduced emissions of nitrogen oxides (NO_x) and particulate matter (PM) relative to traditional fossil fuels (4). Conversely, CBG is produced through the anaerobic digestion of organic matter (agricultural residues, food waste, sewage, landfill emissions), followed by biogas upgrading and compression to yield high-purity biomethane suitable for vehicular use (5). CBG offers the dual benefits of providing a renewable energy source and mitigating greenhouse gas (GHG) emissions through methane capture. Despite their similar chemical composition (predominantly methane), CNG and CBG differ significantly in their origins and

production pathways (6). Both fuels are compatible with modified internal combustion engines and exhibit cleaner combustion characteristics, particularly regarding PM emissions, contributing to improved urban air quality. Empirical research has documented the advantages of CNG and CBG utilization, including improved fuel economy, reduced exhaust emissions, and enhanced energy security (7-10). Advancements in gas storage and fueling infrastructure further support their broader deployment in transportation systems and beyond. This paper provides a comprehensive review of the potential for CNG and CBG adoption in Nigeria, considering their safety aspects, benefits across environmental, economic, and energy security domains, and challenges associated with their implementation.

Table 1. Comparative Overview of Compressed Natural Gas (CNG) and Compressed Biomethane Gas (CBG) as Alternative Fuels

Primary Source	Fossil natural gas from underground reservoirs	Organic waste(agricultural, municipal, landfill)
Production Process	Extraction, purification, compression (200 –250 bar)	Anaerobic digestion → Biogas upgrading → Compression
Main Component	Methane (CH ₄)	Methane (CH ₄)
Renewability	Non-renewable	Renewable
Environmental Benefit	Lower emissions compared to petrol/diesel	Carbon-neutral; methane capture reduces GHGs
Typical Applications	Buses, trucks, cars, stationary power generation	Same as CNG + strong waste management benefits
Challenges	Fossil dependency, supply volatility	Feedstock variability, upgrading costs
LifecycleGHG impact	Moderate reduction	Significant reduction, potential carbon negativity

2. CHEMICAL COMPOSITION AND PRODUCTION PATHWAYS OF CNG AND CBG

The chemical composition of Compressed Natural Gas (CNG) and Compressed Biomethane Gas (CBG) is a critical aspect influencing their performance and environmental impact. While both are predominantly composed of methane (CH₄), their production pathways and associated minor constituents necessitate careful consideration. Biomethane production involves anaerobic digestion of organic feedstocks, followed by biogas upgrading processes to enhance methane concentration and remove impurities such as carbon dioxide (CO₂), hydrogen sulfide (H₂S), and water vapor (Cachia et al., 2018; Abanades et al., 2021; Tonrangklang et al., 2021). This multi-stage purification distinguishes CBG from conventionally sourced natural gas, which undergoes extraction, purification, and compression. Despite these differences in origin and processing, the final biomethane product is chemically identical to fossil-derived methane, making it a renewable substitute for natural gas in various applications, including vehicular fuel (CBG) and injection into natural gas grids (Cucchiella et al., 2017; Tanat et al., 2021). The integration of biomethane into decentralized energy systems via local biogas distribution networks further highlights its versatility. The production of biomethane has garnered policy and economic support, particularly in Europe, for grid injection and biofuel applications, with methodologies including anaerobic digestion, catalytic methanation, and advanced upgrading technologies (11-13), resulting in high-quality biomethane suitable for direct combustion or use in combined heat and power (CHP) units (14). Both CNG and CBG require purification to meet stringent quality standards for compression, storage, and transportation. For natural gas, membrane separation, pressure swing adsorption (PSA), and Metal-Organic Frameworks (MOFs) are employed to enhance purity and efficiency (19-20), optimizing gas quality while minimizing energy

inputs (20). Biogas purification utilizes chemical absorption, physical adsorption, and biological removal to enrich methane and eliminate contaminants (22), with innovative methods like enzymatic pretreatment and hybrid systems under exploration to improve yields and performance. The complex purification and upgrading processes for both natural gas and biogas are crucial for enhancing compositional quality, energy efficiency, and enabling their broader application in sustainable energy systems, contributing to environmental conservation and the low-carbon energy transition.

3. SAFETY AND BENEFITS OF ADOPTING CNG AND CBG AS ENERGY AND TRANSPORT FUELS

3.1 Environmental Impact Assessment

3.1.1 Reduction in Greenhouse Gas Emissions

Compressed Natural Gas (CNG) and Compressed Biomethane Gas (CBG) are increasingly recognized for their comparatively low carbon intensity, establishing them as environmentally preferable alternatives to conventional petroleum-derived fuels. Empirical evidence (21) demonstrates that CNG-powered vehicles exhibit significantly reduced greenhouse gas (GHG) emissions compared to gasoline or diesel vehicles. Furthermore, CBG, derived from renewable organic sources, offers the potential for near-net-zero or even negative GHG emissions on a lifecycle basis, particularly when considering methane capture from waste streams (5). This substantial decrease in emissions underscores the critical role of CNG and CBG in mitigating atmospheric pollution and contributing significantly to global climate change mitigation efforts.

3.1.2 Enhancement of Air Quality

The integration of CNG and CBG as vehicular and engine fuels results in notable reductions in the emission of particulate matter (PM), nitrogen oxides (NO_x), and volatile organic compounds (VOCs). These decreases in atmospheric pollutants lead to measurable improvements in ambient air quality, particularly within densely populated urban environments. Research findings (24) corroborate that vehicles powered by CNG and CBG contribute substantially to the reduction of urban air pollution, consequently enhancing public health outcomes and environmental conditions.

3.2 Advancing Energy Security

3.2.1 Reduced Dependency on Imported Petroleum

Numerous nations, including Nigeria, demonstrate a significant dependence on imported petroleum products to satisfy their energy and transportation requirements, thereby exposing them to the fluctuations of international oil markets and geopolitical instabilities. The transition towards domestically available energy resources, such as natural gas (for CNG production) and biomass (for CBG production), offers a strategic avenue to mitigate this external reliance. As highlighted by (25), diminishing dependence on imported crude oil enhances national energy security and strengthens economic resilience against global market volatilities.

3.3 Economic Considerations

3.3.1 Cost Competitiveness and Financial Incentives

Natural gas and biomass resources present notable economic advantages, as Compressed Natural Gas (CNG) and Compressed Biomethane Gas (CBG) generally exhibit lower costs compared to gasoline and diesel on an energy-equivalent basis (26). When integrated with supportive governmental policies, such as financial incentives, subsidies, and tax relief for the adoption of CNG/CBG vehicles, these fuels offer a compelling economic rationale for cost savings among individual consumers and commercial fleet operators. A comprehensive report by the U.S. Department of Energy (DOE) corroborates the cost-effectiveness of CNG technologies relative to conventional fuels, further incentivizing their widespread adoption.

3.4 Utilization of Domestic Natural Gas Reserves and Organic Waste Resources

In nations possessing substantial reserves of natural gas and organic biomass, such as Nigeria, the strategic deployment of CNG and CBG for both transportation and electricity generation constitutes a critical opportunity to capitalize on indigenous energy resources (27-28). The exploitation of domestic natural gas and biomass reserves offers significant economic and environmental benefits. Furthermore, as the global energy landscape increasingly transitions towards a hydrogen economy, fuel cell technologies, and renewable energy systems, the long-term

sustainability of crude oil as a primary source of foreign exchange is becoming increasingly precarious. Consequently, it is imperative that the Nigerian government expedite the development and integration of CNG and CBG infrastructures alongside broader renewable energy initiatives to ensure sustainable national energy security and economic stability.

4. CHALLENGES AND BARRIERS TO CNG AND CBG ADOPTION IN NIGERIA

4.1 Infrastructure Development

4.1.1 Availability of Refueling Stations

A primary impediment to the widespread adoption of CNG and CBG as mainstream energy carriers and automotive fuels is the limited availability of dedicated dispensing stations (29). The establishment of a reliable and extensive network of CNG/CBG refueling facilities is crucial for supporting the operational viability of CNG/CBG-powered vehicles (30). The pace and extent of CNG/CBG infrastructure development exhibit regional variability, often influenced by government policies, regulatory frameworks, and financial incentives. Ensuring the strategic distribution and accessibility of refueling stations is indispensable for overcoming infrastructural bottlenecks and fostering market penetration (31).

4.1.2 Pipeline Infrastructure

The distribution of CNG is intrinsically dependent on a robust pipeline infrastructure, facilitating the transfer of natural gas from production or processing sites to downstream refueling stations (31). The availability, capacity, and geographic reach of pipeline networks are critical determinants of market scalability for CNG-based applications. The systematic development, modernization, and maintenance of pipeline systems are paramount to ensuring the reliable delivery of CNG, thereby supporting the expansion of dispensing station networks and enhancing energy accessibility (33). The nascent stage of dedicated CBG pipeline infrastructure presents an additional challenge, often requiring localized distribution solutions or blending with existing natural gas networks where feasible.

4.2 Vehicle Performance and Technology

4.2.1 Engine Range and Refueling Time

Vehicles utilizing CNG or CBG may face limitations in driving range compared to their gasoline or diesel counterparts due to the volumetric storage requirements of compressed gaseous fuels (32). This can be a significant challenge for long-distance transport applications. Continuous advancements by automotive manufacturers and researchers are imperative to enhance the efficiency and extend the driving ranges of CNG/CBG vehicles. Additionally, refueling times for gaseous fuels can sometimes be longer than for liquid fuels, requiring technological innovations such as fast-fill systems to improve user convenience (33).

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

5.1 Insights from Global Leaders in CNG/CBG Adoption

India

India has demonstrated significant success in CNG and CBG deployment through comprehensive policies, regulatory frameworks, and extensive refueling infrastructure development in metropolitan areas (35, 37). The large-scale adoption, particularly in public transit, has yielded substantial emission reductions and improved urban air quality (38).

Pakistan

Faced with energy challenges and air pollution, Pakistan aggressively developed CNG infrastructure and incentivized vehicle retrofitting, significantly reducing reliance on conventional fuels and lowering GHG emissions (39-41).

Argentina

Argentina actively promoted CNG adoption in public and private transportation through governmental incentives, leading to widespread CNG vehicle use, reduced carbon emissions, and economic benefits for consumers (42-44).

These case studies highlight the importance of strong governmental support, strategic infrastructure investment, and public awareness campaigns in facilitating the successful adoption of CNG and CBG as viable energy and transport fuels.

6. PROPOSED STRATEGIES FOR THE WIDESPREAD ADOPTION OF CNG AND CBG AS ALTERNATIVE ENERGY FUELS IN NIGERIA

6.1 Policy Framework and Government Support

The Nigerian government needs to design and enforce supportive policy structures and regulatory mechanisms that incentivize the transition to CNG and CBG (45-46). This includes establishing clear targets, streamlining permitting processes, and providing financial incentives for infrastructure development and vehicle conversion.

6.2 Infrastructure Enhancement

Significant investment is required to establish an efficient and expansive refueling station network and a comprehensive pipeline distribution system (47-48). Public-private partnerships (PPPs) can play a crucial role in accelerating infrastructure development.

6.3 Technological Innovation and Development

Supporting research and technological advancements in CNG and CBG production, storage, and utilization is essential (49). Establishing specialized centers within Nigerian universities for engine conversion and training can build local expertise and create job opportunities. Government support for affordable conversion kits is also crucial.

6.4 Financial Support and Incentives

Financial incentives, such as subsidies and grants for infrastructure development and vehicle conversion, are necessary to catalyze adoption (Singh & Tiwari, 2020, 50). Fiscal incentives for consumers and industries investing in biogas plants and CNG conversion kits can significantly reduce the economic burden of transition.

6.5 Public Awareness and Educational Initiatives

Comprehensive educational campaigns targeting vehicle manufacturers, fleet operators, and end-users are vital for fostering consumer acceptance and dispelling misconceptions (51-52).

6.6 Collaborative Efforts and Partnerships

Collaboration between government bodies, private sector stakeholders, and academic institutions is crucial for the successful implementation of CNG and CBG technologies (53). PPPs can accelerate infrastructure rollout and facilitate the exchange of technological knowledge.

7. CONCLUSION

The integration of Compressed Natural Gas (CNG) and Compressed Biomethane Gas (CBG) into automotive and engine technologies offers significant environmental advantages, including the reduction of greenhouse gas emissions, diminished particulate matter and nitrogen oxide (NOx) emissions, and quieter engine operation, contributing to enhanced air quality and reduced noise pollution in urban environments. Driven by their environmental merits, bolstered energy security potential, and economic feasibility, CNG and CBG represent compelling alternative fuel options that promote sustainability and improve public health within the energy and transportation sectors. By strategically adopting CNG and CBG technologies, Nigeria can mitigate its dependence on volatile global crude oil markets, expedite its transition toward a more sustainable, secure, and economically viable energy future, while simultaneously advancing public health outcomes.

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