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AN OVERVIEW OF KEY SAFETY CONCERNS AND SUSTAINABILITY OF CNG RETROFITTED VEHICLES IN NIGERIA

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ABSTRACT

Compressed natural gas (CNG) is increasingly being advocated and adopted as an alternative fuel for vehicles in Nigeria due to its economic and environmental benefits. However, the retrofitting of vehicles to use CNG has raised safety concerns, particularly in a country like Nigeria where regulatory standards, enforcement, and public awareness may not be fully developed. An assessment of the key safety and sustainability of retrofitted CNG vehicles (CNGVs) focusing on factors such as the quality and durability of conversion kits and tanks, proper installation procedures, CNG storage, and refuelling are considered. While CNG is generally safer than traditional fuels like gasoline and diesel—requiring higher ignition temperatures and presenting less fire risk during leaks, the fear of regulatory oversight, inadequate safety standards, and limited technical expertise in vehicle retrofitting may pose significant challenges. Stronger regulations, public awareness campaigns, and technician training programs are advocated to ensure safe CNGV operations in Nigeria.

Keywords: CNG safety, Vehicle retrofitting, Alternative fuel, Regulatory standards, Risk management

INTRODUCTION

As global attention shifts toward reducing carbon emissions and adopting cleaner energy sources, Nigeria has explored alternative fuels such as CNG for vehicle use. CNG offers several advantages, including reduced greenhouse gas emissions, lower fuel costs, and availability from Nigeria's abundant natural gas reserves (Igbojionu et al., 2019). Retrofitting vehicles to support CNG usage as an alternative to gasoline or diesel has generated significant safety concerns among many Nigerians. The concerns were heightened by a recent CNGV explosion in the country (Ochoga, 2024) and the reported plan of some countries, in particular, Malaysia to ban the use of CNGVs in 2025 over safety concerns (Sanusi, 2024). As the use and retrofitting of vehicles that run on fossil fuels to vehicles that run on CNG gain more attention in many countries across the globe (Liu et al. 2022), this paper examines the safety issues associated with CNG retrofitted vehicles and proposes strategies for mitigating them to facilitate safe adoption of CNGVs in Nigeria.

Compressed Natural Gas as a Vehicle Fuel

CNG is a mixture of hydrocarbons, primarily methane, stored at high pressure (typically around 200-250 bar) in specially designed tanks onboard vehicles. The key advantages of CNG include lower emissions of CO_2, NO_x, and particulate matter, compared to gasoline and diesel. Its low flammability range (5-15% volume in air) and higher ignition temperature which is around 540 °C, make it safer than gasoline in many conditions.

CNG Adoption as a Vehicle Fuel in Nigeria

Increased energy demand, environmental concerns, and dwindling fossil fuel reserves have necessitated the search for more sustainable and environmentally friendly alternative sources of energy (Molua et al., 2023). As the emission of greenhouse gases such as carbon dioxide is directly proportional to the amount of fossil fuels consumed by vehicles (Raheem et al, 2024), Nigeria's energy policy has evolved. Increased emphasis is laid on leveraging natural gas as part of the country's transition to cleaner energy. Government initiatives such as the National Gas Expansion Programme (NGEP) aim to promote the use of CNG in transportation, industrial, and domestic applications have gained momentum. However, the adoption of CNG as a vehicle fuel in Nigeria has been slow due to concerns surrounding the conversion process, lack of infrastructure, and potential safety risks in retrofitting vehicles originally designed for gasoline or diesel (Ibeneme et al., 2020; Igbojionu et al., 2019). Vehicle retrofitting from gasoline or diesel to CNG typically involves installing a conversion kit comprising a CNG storage tank and its accessories and modifying the fuel system to allow the engine to use CNG as an alternative fuel. While this process is straightforward in theory, it presents technical challenges and safety risks if not properly managed. These risks can be escalated by the scarcity of certified technicians and standardized retrofitting practices. In Nigeria, the need to adopt alternative automobile fuels other than petrol and diesel in Nigeria was based on the rising costs, perennial scarcity of petrol, and diesel, and environmental considerations (Igbojionu et al., 2019). Since the removal of fuel subsidies by the Federal Government of Nigeria, which caused petrol prices to increase by about 600% in less than 2 years, transportation costs and other commodity prices have skyrocketed. Hence, as a measure toward lowering transportation costs which have a direct effect on the prices of essential commodities, the Federal Government introduced a vehicle conversion initiative aimed at converting fossil fuel-driven vehicles to CNG-driven vehicles. Under the initiative, vehicle owners are encouraged to convert their vehicles at designated conversion centres across the country. Figure 1 compares the dissipation rate, lightness, and fire risks of CNG, liquified Petroleum gas (LPG), and petrol (or gasoline).

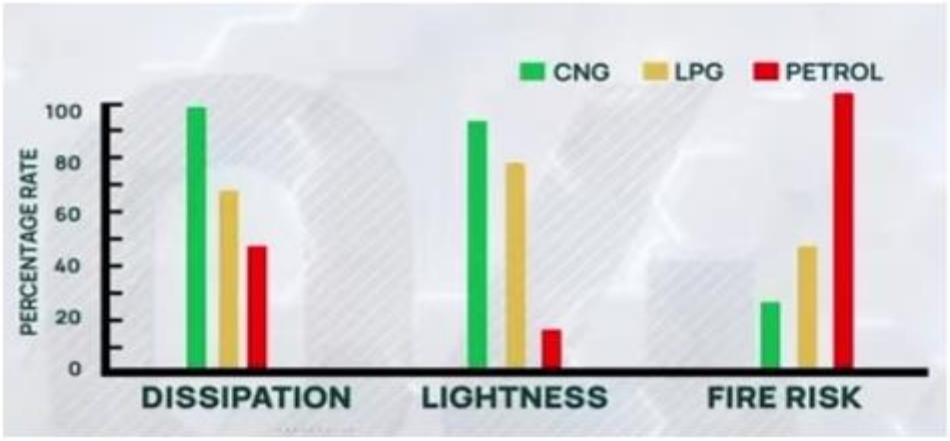

Figure 1: A comparison of the dissipation rate, lightness and fire risks of CNG, LPG and gasoline (Presidential Compressed Natural Gas Initiative, 2024)

Figure 1 shows that CNG has a higher dissipation rate of 50 % and 30% than petrol and LPG respectively. CNG has better dissipation because it is lighter than air, so it dissipates quickly in case of a leak, reducing fire risks. However, the use of high-pressure gas storage in CNGVs presents a unique set of safety challenges, particularly when exposed to extreme temperatures and environmental stresses. The behavior of the CNG storage system under such conditions is of particular concern, as failures can result in leaks or explosions.

The CNG Fuelling system

A CNG system supplies fuel to internal combustion engines (ICE). To make the tank volume sufficiently and conveniently small to fit into vehicles, the gas is compressed to about 200 bar in high-pressure gas tanks interconnected using a manifold. CNG fuel systems deliver fuel to the ICE as a result of the stored pressure in the fuel tank (Berghmans, 2014). In CNGVs, there are no fuel pumps or compressors. As CNG moves from the tanks to the engine, its pressure is reduced to slightly above the atmospheric (Nelson, 2002). ICEs use spark ignition engine technology to ignite the CNG/air mixture in the ICE. The CNG system also has an automatic shutoff valve that closes to interrupt CNG flow if the ICE stops for any reason. CNG systems have a pressure regulator that reduces the fuel supply pressure to the pressure required by the ICE and a check valve to prevent gas from flowing back to the CNG fill connection. According to the Alternative Fuels Data Center, AFDC (AFDC, n.d.), based on storage capacity and compressor size, which determine the quantity and the time it takes for the fuel to be delivered, there are three types of CNG fuelling stations: time-fill, fast-fill CNG fuelling stations and a combination of the two. In fast-fill CNG stations, the gas is stored at high service pressure to fill vehicles very quickly. In time-fill stations, a fuel line from a utility delivers CNG at low pressures to a compressor on site over a specified time, usually overnight. The combination-fill CNG station as shown in Figure 2, combines the features of the fast and time-fill stations with provisions made for filling a variety of CNGVs.

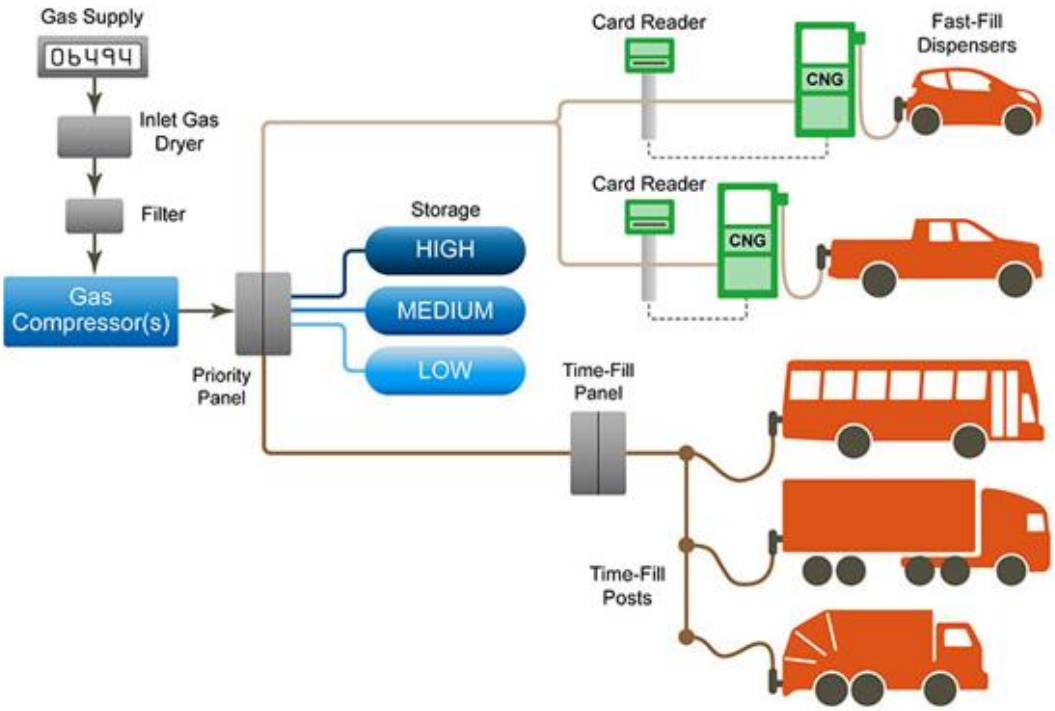

Figure 2: Combination-Fill CNG station (AFDC, n.d.)

Tank Design Considerations

Vehicle CNG tanks are purpose-built to store and deliver natural gas as fuel for vehicles. These tanks replace conventional gasoline or diesel tanks and are commonly installed in the trunk, undercarriage, or bed of the vehicle. CNG tanks are more robust than gasoline or diesel tanks, making them less prone to damage in vehicle accidents (Ibeneme et al. 2020).

Constructed from high-strength steel or composite materials, CNG tanks are designed to withstand the high pressure and challenging conditions of vehicle use (Bhattacharjee et al. 2010). Hence, CNG tanks are more durable than gasoline and diesel tanks as they undergo rigorous safety tests, are made from a single piece of steel alloy (without welded joints), and have discs that rupture in case of impacts, fire, and other potential hazards by preventing extreme pressures in the tank. However, CNG tanks have a safe usage lifespan of approximately 15 to 20 years only (AFDC, n.d.; Sanusi, 2024) and are required to meet stringent safety standards to ensure safe operation. This involves testing for leaks, inspecting for damage or wear, and confirming proper installation and maintenance (Ogunlowo et al., 2015). The International Organization for Standardization (ISO), ISO 11439: High-pressure gas tanks for on-board storage of natural gas as a fuel for automotive vehicles are standardized based on the specifications of ISO 11439 (11439, n.d.).

Additionally, vehicles equipped with CNG tanks must comply with specific safety regulations, including pressure relief devices and shut-off valves. Compared to ordinary petrol tanks, CNG tanks are safer because CNG tanks are designed and fabricated using special materials that can resist high pressures, with a safety factor that is usually > 2. (Nelson, 2002). CNG tanks are commonly classified according to their volume, which in turn determines their range for vehicles or usage duration for various applications. There are four types of CNG tank designs as shown in Table 1.

Table 1: Types and characteristics of CNG tanks (Imran et al., 2015; Industries, 2023)

Tank	Description	Capacity (Gasoline gallon equivalent)	Cost (%)	Application
Type-1	Metallic (Aluminium or steel)	8 to 20	40	Small passenger vehicles
Type-2	Metal liner (hoop-wrapped)	15 to 25	80-95	Compact vehicles, buses, light-duty trucks
Type-3	Metal liner (fully wrapped),	30 to 50	90-100	Passenger vehicles, light and medium-duty trucks, commercial fleets
Type-4	All composite	40 to 60	90	Buses, medium and heavy-duty trucks, industrial use

When choosing a CNG tank, several factors need to be considered to ensure the optimal fit. Such factors include desired application, space constraints, range requirements, weight and payload, and refuelling infrastructure specifications. Due to their high strength-to-weight ratios, type I CNG tanks are produced using high-strength steels according to BS 5045 and AISI 4340 standards. Prototypes undergo extensive testing according to ISO 11439 including burst, pressure cycling, leak, and fire resistance tests to ensure safety.

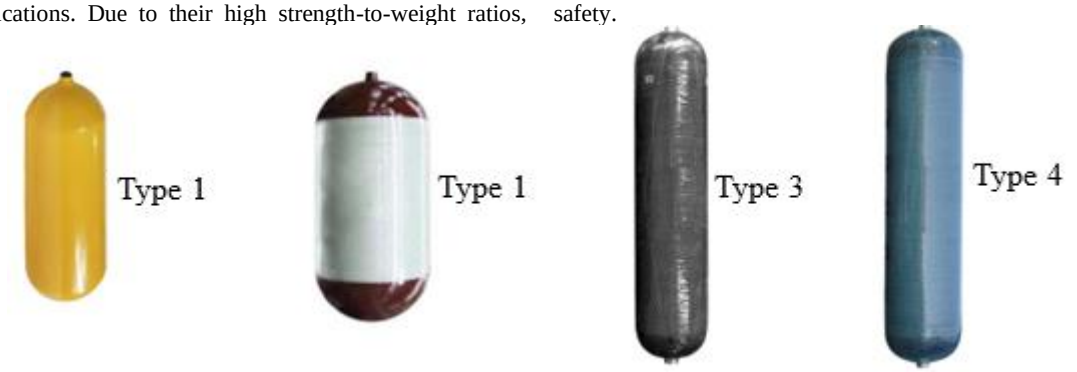

Figure 3: Types of CNG tanks

As shown in Figure 4, CNG tanks have several safety features including dedicated pressure relief devices (PRDs) and a container shutoff valve. The CNG fuel system has a shutoff valve downstream from the container shutoff valve that can isolate all CNG containers from the rest of the CNG fuel system. Current CNG tanks are rated at 250 bar maximum operating pressure, but tests are underway for tanks with up to 690 bar. Damages to CNG tanks are categorized as cuts, scratches, abrasions, and gouges; fire or chemical damages, impacts, delamination, and weathering (Presidential Compressed Natural Gas Initiative, 2024).

Figure 4: Some typical safety features attached to CNG tank (Presidential Compressed Natural Gas Initiative, 2024)

Key Safety Concerns on CNG Retrofitted Vehicles

Since CNG is a gas, it disperses into the air in the event of a leak, unlike gasoline, which can form a hazardous fuel pool, thus reducing the likelihood of fire in such situations.(Ibeneme et al., 2020). For Pakistan, a country with a high number of CNG retrofitted vehicles, a quantitative analysis of the risks of CNG as a transportation fuel by Ali *et al.* (Ali et al., 2024) revealed a heightened risk level of explosion within the CNG sub-sector due to the combustible nature of CNG. However, compared to other fuel sources, the study obtained a relatively lower risk level with an overall risk index of 0.266. the most widely publicized CNGV explosions as shown in Figure 5 are all linked to the CNG tank in the vehicles (Horn, 2019; Ochoga, 2024; Siqqique, 2018).

Figure 5: Scenes of a CNGV explosions at (a) Mumbai, India (Siqqique, 2018) (b) Achem, Germany (Horn, 2019) (c) Benin City, Nigeria (Ochoga, 2024)

The major safety concerns on CNG retrofitted vehicles border on the following areas:

CNG Tank Failure

The failure of a CNG tank is the event of most concern for the CNG fuel system. The severity of CNG tank failures ranges from an intermittent leak to a fragmented rupture of the tank. Essentially all in-service ruptures of CNG tanks have occurred at or shortly after the completion of filling, when pressure within the tanks is at a maximum. CNG tank failures have also occurred because of exposure to fires.

Failure modes that have been observed for CNG tanks include intermittent leaks, continuous leaks, fractures, ruptures, and fragmentation ruptures. An intermittent leak occurs when a fatigue crack propagates through the tank wall as a result of pressure changes associated with repeated filling cycles. When a tank with a fatigue crack is at its maximum pressure, the crack is forced open, and the tank leaks. Intermittent leaks have been reported in all-metal tanks. Also, continuous leaks have been observed in Type 4 tanks as a result of plastic liner defects. The flow rate is typically very low for continuous leaks. A fracture results in a larger opening and a more rapid depressurization than that associated with a continuous leak. In a rupture, the failed tank remains in one piece, but damages, injuries, and fatalities can result from articles being propelled by the gas escaping at a high velocity. In fragmented rupture, the tank breaks into pieces. A risk assessment of CNGVs by (Ali et al., 2024) identified poor quality of CNG tanks as a significant contributor to the risks in the CNG industry due to the higher possibility of explosions. Thus, the highest percentage of accidents involving CNGVs are related to the explosion of gas the gas tanks. Table 2 highlights some of the most common factors that can cause CNG tank explosions.

Table 2: Common causes of CNG tank explosions

Factor	Comments
Unprofessional Installation	Poor, unprofessionally done connections between the tank, valves, and pipes can increase the risk of an explosion.
Tank Storage	Poor tank Storage can weaken the tank structure increasing the risk of explosion.
Accidents	Damage in an accident can cause rupture and gas leaks from the tank.
Elevated Temperatures	Expansions due to extreme heat can weaken tanks and worsen the high pressure CNG under which CNG is stored.
Leakages	Accumulated gas in an enclosed space, can create a highly flammable environment, especially in the event of a spark.
Substandard Kits	Substandard kits may lack essential safety features and thus can cause malfunctions.
Tank limits	Filling the tank beyond the recommended pressure can lead to pressure-release valve failure.
Corrosion	Over time, the tanks can rust compromising their structural integrity, potentially leading to a rupture.
Lack of maintenance	Unnoticed wear and tear on tank accessories can lead to gas leaks or pressure build-up, which can cause an explosion.

High Pressure CNG Storage

One of the primary safety concerns with CNG retrofitted vehicles is the storage of CNG at high pressure. CNG is typically stored in tanks at pressures up to 200-250 bar, which can pose a risk of explosion if the tank is damaged or improperly installed. In Nigeria, where vehicle maintenance is often challenging and with inadequate and road conditions mostly bumpy, ensuring the durability and correct installation of CNG tanks is critical in preventing the CNG tank explosion.

Conversion Kits and Tank Integrity

CNG conversion kits must meet minimum specification standards while the CNG tanks in particular must meet specific international standards to ensure they can withstand high pressure without rupture. The specifications, performance, and general test methods for CNG fuel system components applicable to all CNGVs are defined by ISO 15500-2:2016. In Nigeria, there is concern about the quality of some of the retrofitting components used, as substandard materials may increase the likelihood of tank failure. Proper regulation and certification of both the equipment used and the professionals performing the retrofitting are essential to minimize the risk of tank-related accidents.

CNG Ignition and Combustibility

CNG is less combustible than gasoline, with ignition only possible when its concentration in air is between 5% and 15%. Additionally, CNG requires a higher ignition temperature of approximately 680°C compared to gasoline, which ignites between 230°C and 280°C (Ogunlowo et al., 2015). These properties make CNG inherently safer in some respects. However, in the event of a leak, CNG's rapid dispersion in the air may pose a different kind of risk, particularly in enclosed spaces where a build-up of gas could lead to an explosive atmosphere if exposed to a spark. In Nigeria, where many vehicles are parked in tight or poorly ventilated areas, proper leak detection systems and regular maintenance of the CNG system are necessary to prevent the build-up of combustible mixtures in confined spaces.

Refuelling Infrastructure

The availability of dedicated CNG refuelling stations in Nigeria remains limited, leading to potential safety hazards during refuelling. Given the high pressure under which CNG is stored, improper refuelling practices can result in over-pressurization, leaks, or other dangerous conditions. There are safety concerns related to the need for the training of refuelling station attendants to follow proper safety protocols which are essential in mitigating these risks. Moreover, low public awareness of safe refuelling practices is another safety concern that can increase the risk of accidents during the refueling process.

Vehicle Retrofitting Standards

A critical safety concern is the lack of standardized vehicle retrofitting processes in Nigeria. Currently, there are indications of some vehicle conversions taking place at unlicensed workshops, which may not adhere to international CNGV safety standards as adopted by the Standards Organization of Nigeria (SON). This increases the likelihood of improper installation, which can result in gas leaks, mechanical failures, or other safety hazards. There is an urgent need for the Nigerian government to establish more stringent regulatory frameworks that mandate the certification of retrofitters, the use of high-quality equipment, and adherence to best practices for CNG conversion.

Reckless driving habits

Excessive overloading, over-speeding, and other reckless driving habits are common causes of accidents. Since overloading can affect a vehicle's balance and sudden jerks or unwarranted shocks can potentially impact a vehicle's CNG systems, the use of CNG in vehicles can exacerbate the situation. There are safety concerns when CNGVs are handled by reckless and negligent drivers, many of the safety compromises Nigerian drivers make in handling gasoline-fuelled vehicles may be disastrous when tried with CNGVs.

Recommended Solutions for Improving the Safety and Sustainability of Retrofitted CNGVs in Nigeria

By combining infrastructural investment, supportive policy measures, and public engagement, the acceptability of the safety of CNGVs in Nigeria can be significantly improved, contributing to a cleaner, more sustainable transportation system. The initiative requires a multi-faceted approach that addresses economic, social, infrastructural, and policy-related barriers. Some key strategies for addressing the safety concerns of CNGVs in Nigeria should include:

Infrastructure Development

Expand CNG Refuelling Stations: The availability of refuelling infrastructure is a critical factor. Governments and private sectors should invest in building a widespread network of CNG stations, especially along major transport corridors and in urban areas.

Improved Maintenance Facilities: Provide easy access to maintenance centers specializing in CNGVs, including

trained technicians and standard spare parts, to reduce concerns about vehicle upkeep.

Government Incentives and Policy Support

Subsidies and Tax Incentives: Offer subsidies or tax reductions on CNGVs and refuelling stations to lower the initial cost for consumers and investors. For example, waiving import duties on CNG conversion kits or CNG-compatible vehicles.

Regulatory Support: Enforce policies that encourage the use of CNGVs, such as stricter emission regulations that favours cleaner fuels or mandating the conversion of public transport to CNG.

Public-Private Partnerships: Encourage collaborations between governments and private companies to share investment and operational risks in building CNG infrastructure and promoting its usage.

Financial Mechanisms for Consumers

The government should introduce low-interest loans, flexible payment plans, or leasing options to make CNGVs more financially accessible, particularly to low- and middle-income consumers. Additionally, financial assistance or rebates should be offered to consumers who are willing to convert their petrol or diesel vehicles to CNG to lower the entry cost of switching fuel systems.

Public Transport and Commercial Vehicle Conversion

The government should promote converting public transportation fleets (buses, taxis) and commercial vehicles (trucks, delivery vans) to CNG to improve visibility and encourage adoption among private vehicle owners. More pilot projects should be encouraged to drastically improve the current government-backed pilot projects using CNG buses or taxis to demonstrate their viability, reliability, and cost-effectiveness, leading to broader adoption.

Environmental and Health Advocacy

Highlight Environmental Benefits: Emphasis should be laid on the lower emissions of CNG compared to gasoline and diesel, and its positive impact on air quality in densely populated urban centers, reducing health risks like respiratory issues.

Health Awareness Campaigns: there is a need to link the adoption of CNGVs to improved public health outcomes, particularly in cities such as Lagos, Kano, and Port Harcourt that are struggling with air pollution, to drive consumer preference for cleaner alternatives.

Technological and Product Innovations

Vehicle Affordability: The government should encourage further, local manufacturing of CNGVs and conversion kits to reduce costs and adapt the products to local needs and conditions.

Innovative Technologies: The government should support research and development into more efficient and affordable CNG technologies, such as lightweight CNG tanks, hybrid CNG-electric vehicles, or improved CNG engines to increase vehicle performance and appeal.

Long-term Policy Roadmap

Clear Long-term Plans: The government should provide a stable and clear long-term energy policy that supports CNG adoption, encouraging both industry and consumers to invest in the technology with confidence.

Monitoring and Enforcement: The government should also ensure that policies aimed at reducing air pollution and supporting CNG adoption are consistently enforced, with penalties for non-compliance to drive behavioural change.

Regulatory and Technical Solutions

The lack of enforcement of safety standards and quality procedures seriously threatens safety in CNG conversion initiatives (Ali et al., 2024). Safety regulations play a critical role in ensuring that CNGVs can withstand extreme weather conditions. To ensure the safety of CNG retrofitted vehicles, Nigeria must adopt and enforce more stringent safety standards aligned with international best practices. This includes mandating the use of certified CNG conversion kits, tanks, and components, and requiring periodic inspection of CNG systems in vehicles. Additionally, retrofitting workshops should be licensed and regularly audited to ensure compliance with safety protocols.

The Federal Road Safety Corps (FRSC), the Vehicle Inspection Officers (VIO), the Standards Organization of Nigeria (SON), and other regulatory bodies must also collaborate with relevant stakeholders, such as vehicle manufacturers, retrofitters, and CNG suppliers, to develop comprehensive safety guidelines. The guidelines should also be well illustrated and translated into the three dominant local languages of Hausa, Igbo, and Yoruba.

Awareness Campaigns and Education

Public Awareness Campaigns: Launch awareness programs highlighting the environmental and economic benefits of CNG over conventional fuels, such as reduced greenhouse gas emissions and lower fuel costs. Consumers should be further informed about the safety, reliability, and long-term savings associated with CNGVs through media campaigns, workshops, and exhibitions. The success of CNG adoption in Nigeria will depend not only on technical and regulatory solutions but also on public understanding of CNG's benefits and risks. Public awareness campaigns should focus on educating vehicle owners about the importance of using certified conversion centres, maintaining their CNG systems regularly, and adhering to safe refuelling practices. A well-informed public will be more likely to prioritize safety in the adoption of CNGVs.

Training and Certification of Technicians: One of the most effective ways to improve the safety of CNG retrofitted vehicles is by ensuring that only trained and certified technicians perform the conversions. Certification should be mandatory, and ongoing professional development should be encouraged to keep technicians up-to-date with the latest safety standards. By ensuring that only trained and certified technicians perform the conversions. This will require the development of specialized training programs in partnership with Universities, polytechnics other technical institutions, and industry stakeholders. Certification should be mandatory, and ongoing professional development should be encouraged to keep technicians up-to-date with the latest safety standards.

Maintenance and Inspection

High-pressure cylinders and tanks require periodic inspection and consequent certification. A special section in the vehicle inspection department should be created for the regular inspection and certification of CNGVs. Proper records of the inspections should be documented and made a compulsory accompanying document for the transfer of ownership of the vehicle.

CONCLUSION

As Nigeria embraces compressed natural gas as an alternative fuel, addressing the safety concerns associated with CNG

retrofitted vehicles is critical to ensuring the successful and sustainable adoption of this technology. By enforcing stringent safety standards, training certified technicians, and raising public awareness, Nigeria can mitigate the risks associated with CNGV conversion and operation. Ensuring safety in this transition will pave the way for the broader use of cleaner and more affordable energy in Nigeria's transportation sector. By addressing the safety concerns highlighted in this study, Nigeria can fully harness the potential of CNG as a cleaner, safer, and more sustainable fuel alternative. The best practices and regulatory frameworks highlighted in this study are necessary to address safety concerns and ensure the safe and sustainable adoption of CNG as a fuel for vehicles in Nigeria.

REFERENCES

AFDC. Compressed Natural Gas Fueling Stations. [Online]. https://afdc.energy.gov/fuels/natural-gas-cng-stations.

Ali Y., Younus A., Ullah A., & Alrefai A. H. (2024). Journal of Safety Science and Resilience Compressed Natural Gas (CNG) as a fuel and the associated risks : A quantitative analysis in the scenario of a developing country. *Journal of Safety Science and Resilience*, 5(3), 306–316. https://doi.org/10.1016/j.jnlssr.2024.05.001.

B
hattacharjee G., Bhattacharya S., Neogi S. & Das S. K. (2010). CNG cylinder burst in a bus during gas filling – Lesson learned. *Safety Science*, 48(10), 1516–1519. https://doi.org/10.1016/j.ssci.2010.05.002.

Berghmans J., & Maarten V. (2014). Safety aspects of CNG cars. International Symposium on Safety Science and Technology. *Procedia Engineering*, 84, 33 – 46. https://www.sciencedirect.com/science/article/pii/S1877705814017287/pdf?md5=e9a66b01566bf175e939c72fa02554e4&pid=1-s2.0-S1877705814017287-main.pdf.

Horn L. (2019). Accident at Gas Station in Achern: Audi A3 Explodes while Refueling with Natural Gas. *Focus Online*. [Online]. https://m.focus.de/auto/ratgeber/sicherheit/ursache-fuer-audi-a3-gasexplosion-an-heiligabend-gefunden_id_10202289.html.

Ibeneme I. O., Harcourt, P., & Ighalo, J. O. (2020). Implementation of CNG as an Alternative Fuel for Automobiles in Nigeria : Benefits and Recommendations. *International Journal of Engineering*, 9(07), 1516–1522.

Igbojionu A., Anyadiegwu C., Anyanwu E., Obah B., & Muonagor C. (2019). Technical and Economic Evaluation of the Use of CNG as Potential Public Transport Fuel In Nigeria. *Scientific African*, 6, e00212, 1-15. https://doi.org/10.1016/j.sciaf.2019.e00212.

Imran M., Yasmin T. & Shakoor, A. (2015). Technical Overview of Compressed Natural Gas (CNG) as a Transportation Fuel. *Renewable and Sustainable Energy Reviews*, 51, 785–797. https://doi.org/10.1016/j.rser.2015.06.053.

Industries B. (2023). Comparison of CNG Cylinder Sizes: Choosing the Right Fit for Your Needs. [Online]. https://www.suppliercylinder.com/news/comparison-of-cng-cylinder-sizes-choosing-the-right-fit.html.

International Organization for Standardization (ISO), ISO 11439: Gas Cylinders—High-Pressure Cylinders for the On-Board Storage of Natural Gas as a Fuel For Automotive Vehicles. [Online]. https://www.iso.org/standard/44755.html.

Liu H., Khan I. A. & Zakari M. A. (2022). Roles of Trilemma in the World Energy Sector and Transition Towards Sustainable Energy: A Study of Economic Growth and the Environment. *Energy Policy*, 170(1), 1–9. https://doi.org/10.1016/j.enpol.2022.113238.

Molua O. C., Ukpene, A. O., Ighrakpata, F. C., Nwachuku, D. N., Ogwu, D. A. & Edobor, M. (2023). Optimization of Biogas Production from Tree Waste Materials for Bioresource Recovery. *FUDMA Journal of Sciences (FJS)*, 7(6), 209–213. https://doi.org/10.33003/fjs-2023-0706-2118%0A.

Nelson S. C. (2002). Overview of the Safety Issues Associated with the Compressed Natural Gas Fuel System and Electric Drive System in a Heavy Hybrid Electric Vehicle. *Oak Ridge National Laboratory*. [Online]. https://doi.org/10.2172/885594.

Ochoga P. (2024). JUST-IN: Scores Injured As CNG-Powered Vehicle Explodes In Edo. *Leadership*. [Online]. https://leadership.ng/just-in-scores-injured-as-cng-powered-vehicle-explodes-in-edo/.

Ogunlowo O. O., Bristow A. L., & Sohail M. (2015). Developing Compressed Natural Gas as an Automotive Fuel in Nigeria: Lessons from International Markets. *Energy Policy*, 76, 7–17. https://doi.org/10.1016/j.enpol.2014.10.025.

Presidential Compressed Natural Gas Initiative. (2024). PCNGi. [Online]. https://www.facebook.com/share/v/mtHTQNEE39YM3E9C/?mibextid=xfxF2i.

Raheem I. O., Burari, F. W., Salihu, A., Abdulkareem, M. N., Aremu, B. G. and Rabiu, J. A. (2024). Assessment of CO_2 Emission Due to Speed Bumps on Selected Highways in Bauchi State. *FUDMA Journal of Sciences (FJS)*, 8(3), 91–98. https://doi.org/10.33003/fjs-2024-0803-2477.

Sanusi D. (2024). Nigerians Question CNGV Safety after Malaysia Sets 2025 Ban. The Punch Newspaper, https://punchng.com/nigerians-question-cng-vehicle-safety-after-malaysia-sets-2025-ban/.

Siqqique I. (2018). A blast at the CNG pump sends the auto driver flying through the air. Mumbai Mirror. [Online]. https://mumbaimirror.indiatimes.com/mumbai/other/blast-at-cng-pump-sends-auto-driver-flying-through-air/articleshow/66299340.cms.