Factors Shaping the Adoption of Compressed Natural Gas in Vehicles in Tanzania.

Zamela Mussa Kinyami
Field Student, Tanzania Petroleum Development Corporation
P. O Box 1191, Dodoma, Tanzania.
Email: zamelakinyami@gmail.com

Abstract

This study investigates the factors affecting the adoption and usage of compressed natural gas (CNG) in vehicles, emphasizing its potential as a cleaner energy source and the challenges vehicle owners face in its utilization. Using a double hurdle model and descriptive statistics, data were gathered from 100 randomly selected vehicle owners at three major petrol stations in Ilala district, Dar es Salaam, Tanzania. The results indicate that higher education levels and newer vehicles positively impact both the decision to adopt and the extent of CNG usage, while older vehicles and high conversion costs act as barriers. The study also highlights challenges such as inadequate CNG infrastructure, high upfront conversion expenses, and safety concerns. It calls for targeted interventions to improve public awareness, expand refueling networks, and offer financial incentives to encourage the transition to CNG. These efforts could play a crucial role in advancing cleaner and more sustainable energy use in Tanzania's automotive sector.

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1.Introduction

Natural gas (NG), a naturally occurring mixture of hydrocarbons, is recognized as the cleanest fossil fuel and an increasingly essential energy resource worldwide (Dimoso & Andrew, 2021). Methane, its primary component, can be processed to remove impurities, ensuring NG is a safe and efficient energy source when appropriately transported, stored, and utilized (Faramawy et al., 2016). Globally, NG accounts for 23% of primary energy consumption, with reserves estimated at 7,080.3 trillion cubic feet (TCF), sufficient to meet current demands for over 60 years (IEA, 2022; Kitole et al., 2023; BP, 2022). The growing production and consumption of NG are driven by increasing demand for cleaner energy and concerns about environmental sustainability (Najibi et al., 2015).

Natural gas is utilized in various forms, including compressed natural gas (CNG) and liquefied natural gas (LNG), across transportation modes such as road, rail, marine, and aviation (Nijboer, 2010). To address the challenge of its larger storage volume compared to liquid fuels, NG is compressed into high-pressure tanks, enabling its use as CNG in vehicles to replace traditional fuels like petrol and diesel (Faramawy et al., 2016; Khan et al., 2015; Kitole & Utouh, 2023). Governments worldwide are promoting CNG as a cleaner, cost-effective alternative to conventional fuels, contributing to its growing adoption in the transportation sector (Ogunlowo et al., 2015).

However, despite its environmental and economic benefits, the use of NG in vehicles remains limited in many countries, including Tanzania. The global shift toward NG as a transport fuel gained momentum during the 1970s energy crisis, with countries like Brazil implementing policies to make NG significantly cheaper than gasoline to encourage its use (Frick et al., 2007). In Tanzania, the government has introduced fixed CNG pricing through the Tanzania Petroleum Development Corporation (TPDC) and the Energy and Water Utilities Regulatory Authority (EWURA) to promote its adoption. Despite these efforts, the diffusion of CNG technology has been slow, with limited refueling infrastructure and relatively few vehicles converted to CNG since its introduction in 2007 (BP, 2022).

The discovery of 57.54 TCF of natural gas reserves in Tanzania—47.08 TCF offshore and 10.96 TCF onshore—presents a significant opportunity to expand its use in various sectors, including transportation (BP, 2022). Rising global petroleum prices and the growing shift toward cleaner energy sources make NG an attractive option for vehicle owners due to its environmental benefits and cost savings (Curran et al., 2014). However, despite these advantages, adoption remains limited, with 81% of Tanzania's natural gas production allocated to electricity generation and only 19% used for industries, households, and vehicles (Ishengoma & Gabriel, 2021).

The slow adoption of CNG technology in Tanzania is largely attributed to challenges such as limited infrastructure, a lack of refueling stations, and low awareness among vehicle owners. By 2022, only two CNG filling stations had been established in Dar es Salaam, and approximately 1,400 vehicles had been converted to CNG (BP, 2022). This underutilization persists despite CNG's potential to reduce emissions, lower fuel costs, and decrease dependence on imported oil.

Given Tanzania's substantial natural gas reserves and the global drive for cleaner energy, the limited adoption of NG in transportation presents a critical challenge. This study seeks to explore the factors influencing NG usage in vehicles, identify barriers to its adoption, and propose strategies to promote the wider use of CNG in Tanzania’s transport sector, contributing to environmental sustainability and energy efficiency.

2. Theoretical foundation

This study is grounded in the "energy ladder" theory, a widely recognized framework for explaining household energy use in developing countries (Janssen et al., 2006). Originating in the early 2000s through research by Daniel, Pattanayak, and the World Health Organization (WHO) in Sri Lanka, the theory describes a progression in energy choices as household income increases (Muller & Yan, 2016). The energy ladder posits that households transition from traditional fuels like biomass to intermediate fuels such as kerosene and coal, and finally to modern energy sources like natural gas and electricity. This evolution reflects economic theories of consumer behavior, wherein rising purchasing power enables the substitution of inferior goods with more advanced and convenient alternatives (Moshiri, 2015). Thus, the energy ladder model links technological advancement and wealth to shifts in fuel preference (Janssen et al., 2006).

Despite its influence, the energy ladder theory has faced criticism for oversimplifying energy-use patterns. Critics argue that it assumes a linear progression in fuel choices based solely on income, overlooking other determinants such as access, reliability, and cultural preferences. For instance, households may continue using traditional energy sources despite increased income due to availability or ingrained social and cultural practices (Janssen et al., 2006). Additionally, the model inadequately considers gender roles, social hierarchies, and the broader social dynamics that influence energy decisions. Its narrow focus on income-driven transitions also neglects the environmental implications of energy use, failing to emphasize the importance of sustainable and low-carbon energy systems in addressing climate change.

The energy ladder theory is relevant to this study as it provides a framework for understanding income-driven shifts toward adopting compressed natural gas (CNG) in vehicles. Higher-income vehicle owners are more likely to switch to CNG as it becomes more affordable and accessible, reflecting the core principles of the energy ladder (Muller & Yan, 2016). This study applies the theory to Tanzania's automotive sector, where the adoption of CNG aligns with the model’s emphasis on economic growth facilitating the transition to cleaner, more sophisticated energy options. By examining the relationship between income and CNG adoption, this research highlights the theory’s practical application while acknowledging the need to incorporate broader social and environmental factors.

3. Methodology

This study adopted a cross-sectional research design, collecting data from respondents at a single point in time to facilitate efficient comparisons across variables while minimizing costs and time. This approach was well-suited to the study’s objective of identifying factors influencing the adoption of Compressed Natural Gas (CNG) technology among vehicle owners in Ilala District, Dar es Salaam. By providing a snapshot of CNG usage, the design enabled the collection of relevant data for analysis and drew on established methodologies for cost-effective, time-sensitive research (Asenahabi, 2019). Ilala District, chosen as the study area, serves as a major transport hub in Dar es Salaam and hosts one of the region’s few CNG filling stations operated by Anriq Gas Company. The district's population of 1,649,912, according to the 2022 census, spans diverse socio-economic groups, making it an ideal location to study the adoption of CNG technology (Ilala Municipal Council, 2022).

The study targeted vehicle owners in Ilala District, including those who had adopted CNG technology and those who had not. Due to budget and time constraints, the sample focused on vehicle owners frequenting three petrol stations: Big Bon in Kariakoo, Puma Energy in Ilala, and Camel Oil in Buguruni. A sample size of 100 vehicle owners was determined using Yamane's formula, ensuring representativeness. Cluster sampling was employed to select three wards (Mnazi Mmoja, Ilala, and Kariakoo) from the district's 26 wards, and systematic random sampling was applied to select vehicle owners visiting the petrol stations. This approach ensured a fair and unbiased selection process, capturing diverse perspectives on the adoption of CNG technology in the district.

4. Analytical modeling

To analyze the determinants of natural gas usage in vehicles in Dar es Salaam, the double hurdle model was employed. This model is particularly suitable as it accounts for the two-stage decision-making process (Anasel *et al.*, 2024) as vehicle owners undergo: first, the decision to adopt natural gas technology, and second, the extent of its usage. The double hurdle model allows for the separate examination of factors influencing both the adoption and intensity of natural gas use, providing a more nuanced understanding of the variables that drive this behavioral shift.

First hurdle

The probability that vehicle owners in Ilala district to use NG in vehicles is assumed to be determined by an underlying response variable that explains the vehicle owner's demographic, institutional and socio-economic characteristics, thus can be illustrated as:

$$D_i^* = x_i^{'}\beta + \varepsilon_i \quad \ldots\ldots\ldots\ldots 1$$

Where D_i^* is a latent (dependent) variable that shows whether vehicle owner use or not use NG in vehicles, β denotes the vector of unobserved served parameters to be estimated, $x_i^{'}$denote the vector of observed independent covariates explaining the event, lastly ε_i denotes unobserved error term capturing other factors and is assumed to be independent and normally distributed. That is μ_i
N~ (0, 1), and$D_i = 1 \; if \; D_i^* > 0$

$$D_i = 1 \; if \; D_i^* \leq 0$$

The variable D_i present the value of 1 if the vehicle owner users NG and the marginal utility over using NG is greater than not using and zero (0) otherwise. The binary variable D_i is assumed to be a probit model and is specified as:

$$Pr(D_i = 1/x_i)' = \phi(x\beta) + \varepsilon_i \quad \ldots\ldots\ldots\ldots 2$$

Where Pr presents the probability of NG usage among vehicle owners: D_i is the binary variable of NG usage: ϕ denotes the cumulative normal distribution: x is the vector of vehicle owner's demographic, socio-economic and institutional characteristics denote the coefficient to be estimated and ε_i denote the random error term distributed normally with zero mean and constant variance.

The second hurdle

The extent to which the vehicle owner use NGD^* is assumed to be truncated normal distribution with parameters to be different from the Probit model that can be estimated as follows:

$$D^* = x_i'\alpha + \mu_i \ldots\ldots\ldots\ldots 3$$

Where $D^*$is the observed extent of NG usage measured by income of the vehicle owners received in yearly basis from their different income generating activities, $x_i$indicate the vector of covariates that explain the extent, α is a vector of unobserved parameters to be estimated and $\varepsilon_i$is a random variable that denotes all other factors apart from X. Since the assumption of independence of the two error terms, later, it was suggested that the hurdles can be estimated by the maximum likelihood method of Probit and truncated regressions.

Results

The sociodemographic characteristics of the respondents in Table 1 indicate a fairly balanced gender distribution, with 55% male and 45% female respondents. In terms of age, the majority of respondents fall within the 25-34 age group, representing 36%, followed by 24% in the 45-54 age range, and 20% in the 35-44 age group. Only a small percentage of respondents are older, with 2% aged between 55-64 and another 2% between 65-74 years.

Table 1: Sociodemographic characteristics of respondents

Variables	Category	Frequency	Percent	Cumulative Percent
Gender	Male	55	55%	55
	Female	45	45%	100
	Total	**100**	**100.00**%	
Age levels of respondents	15-24	16	16%	16
	25-34	36	36%	52
	35-44	20	20%	72
	45-54	24	24%	96
	55-64	2	2%	98
	65-74	2	2%	100
	Total	**100**	**100.00**%	
Distance to gas station	Near	44	44%	44
	Far	56	56%	100
	Total	**100**	**100.00**%	
Awareness of CNG	Not Aware	30	30%	30
	Aware	70	70%	100
	Total	**100**	**100.00**%	
Education Level	No formal Education	4	4%	4
	High School or Lower	8	8%	12
	College or Diploma	37	37%	49
	Degree Level	46	46%	95
	Master’s or PhD	5	5%	100
	Total	**100**	**100.00**%	
Perception of CNG Cost	Low Cost	43	43%	43
	High Cost	57	57%	100
	Total	**100**	**100.00**%	
Attitude on Environmental Concern	Consider	43	43%	43
	Do Not Consider	57	57%	100
	Total	**100**	**100.00**%	

Regarding the distance to gas stations, 56% of respondents indicated that they live far from a gas station, while 44% reside closer. This distribution highlights a potential challenge in accessing gas refueling stations for many vehicle owners. Moreover, a significant majority (70%) of respondents are aware of compressed natural gas (CNG) technology, while 30% reported not being aware, indicating that while awareness is relatively high, there is still a need for increased information dissemination about CNG.

In terms of education level, most respondents have achieved a high level of education, with 46% holding a degree and 37% having a college diploma. Only 4% of the respondents lack formal education. Regarding perceptions of CNG costs, 57% of respondents view the installation of CNG systems as expensive, and similarly, 57% do not consider environmental factors when deciding on fuel options.

Table 2: Determinants of compressed natural gas (CNG)

Variables	Hurdle I			Hurdle II		
	Coefficient	**Std. Err.**	**P>z**	**Coefficient**	**Std. Err.**	**P>z**
Gender	0.6674	0.3244	0.040	0.2598	0.1324	0.053
Age	0.0216	0.0153	0.158	0.0074	0.0056	0.019
Education level	0.1136	0.0431	0.008	0.0577	0.0180	0.002
Distance from the Gas station	-0.0331	0.0376	0.379	-0.0118	0.0129	0.360
Used years of vehicle	-0.3146	0.0917	0.001	-0.1384	0.0363	0.000
Awareness	-0.4147	0.3363	0.218	-0.2155	0.1363	0.117
Cost of Installing CNG	0.1410	0.3262	0.666	0.0335	0.1319	0.800
Attitude of vehicle owner	0.2295	0.3318	0.489	0.0970	0.1314	0.462
Cost incurred when using petrol	0.0573	0.0000	0.569	0.0906	0.0022	0.768
Cost of using natural gas	-0.0347	0.0800	0.916	0.0382	0.0030	0.927
Observation	100					
Pseudo R^2	0.3288					
P value	0.0000					
Log-likelihood	-44.5701					

Source: Research Data (2023)

The results from the double hurdle model in Table 2 reveal several key factors that influence both the adoption and the intensity of compressed natural gas (CNG) usage among vehicle owners. In the first stage of the model (Hurdle I), which examines the decision to adopt CNG, three variables are statistically significant. Gender plays a positive role, with a coefficient of 0.6674 (p = 0.040), indicating that males are more likely to adopt CNG compared to females. Additionally, education level has a positive and significant effect, with a coefficient of 0.1136 (p = 0.008), suggesting that individuals with higher education levels are more inclined to adopt CNG technology. On the other hand, the used years of the vehicle negatively impact the likelihood of CNG adoption, with a coefficient of -0.3146 (p = 0.001), meaning that older vehicles are less likely to be converted to CNG.

In the second stage of the model (Hurdle II), which examines the intensity of CNG usage, several factors remain significant. Age has a positive effect, with a coefficient of 0.0074 (p = 0.019), indicating that older individuals tend to use CNG more intensively. Education level continues to be an important factor, with a coefficient of 0.0577 ($p = 0.002$), meaning that individuals with higher education are more likely to use CNG more frequently. Similar to Hurdle I, the used years of the vehicle negatively influence the intensity of CNG usage, with a coefficient of -0.1384 ($p = 0.000$), showing that older vehicles are less likely to be used intensively with CNG.

Other variables, such as distance from the gas station, awareness of CNG, and the cost of installing CNG, are not statistically significant in either hurdle. For example, the coefficient for distance is -0.0331 in Hurdle I and -0.0118 in Hurdle II, but both have p-values greater than 0.3, indicating no significant impact on CNG adoption or usage. Similarly, awareness and installation cost do not significantly affect the decision to adopt or the intensity of CNG usage. Overall, the model has a pseudo-R^2 of 0.3288 and is highly significant with a p-value of 0.0000, meaning it effectively explains a substantial portion of the variation in CNG adoption and usage decisions among vehicle owners.

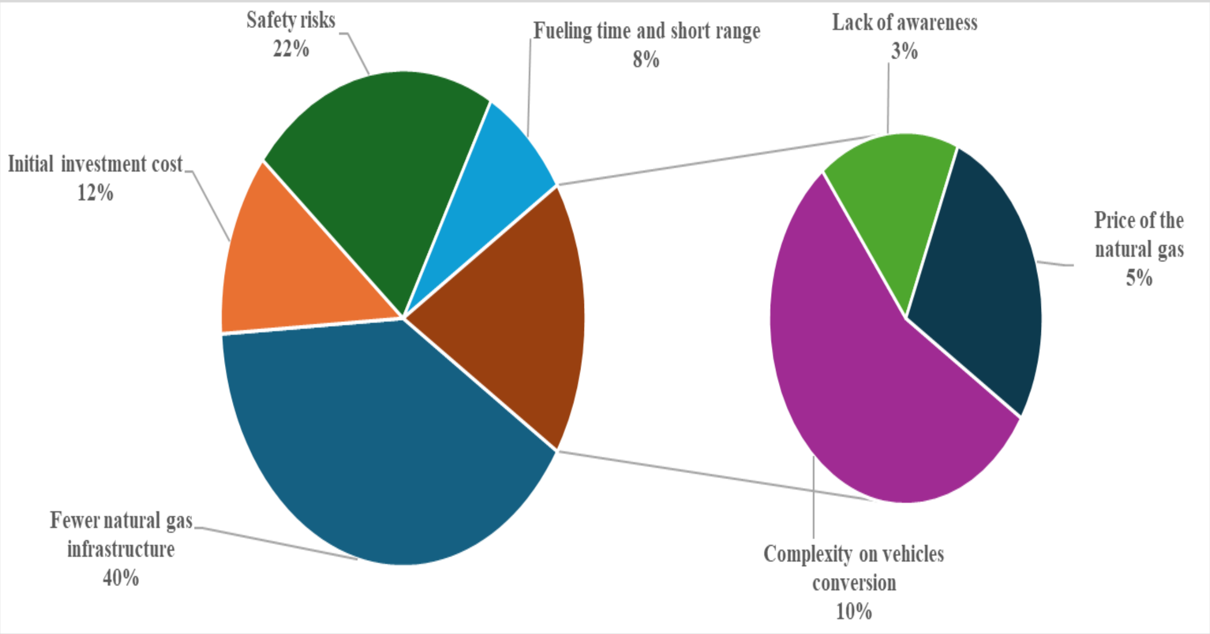

Figure 1: Challenges facing vehicle owners in Natural Gas usage

Source: Source: Research Data (2023)

The challenges faced by vehicle owners in adopting natural gas (CNG) as fuel, as indicated in Figure 1, highlight several significant barriers that hinder widespread usage. The most prominent challenge is the lack of natural gas infrastructure, which affects 40% of vehicle owners. This suggests that the limited availability of refueling stations is a major deterrent, making it difficult for owners to conveniently access CNG. The scarcity of these stations likely adds logistical challenges, such as the need to travel long distances to refuel, which makes natural gas less attractive compared to traditional fuels like gasoline and diesel, which have a well-established refueling infrastructure.

The second major issue is related to safety risks, which concern 22% of vehicle owners. This reflects apprehension about the perceived dangers associated with using CNG, such as the risk of gas leaks or explosions. While CNG is generally considered safe, the lack of widespread use and misinformation may contribute to these concerns. The fear of safety risks could prevent more vehicle owners from converting to or adopting natural gas, especially if these perceptions are not adequately addressed through public awareness campaigns or improved safety measures.

Other notable barriers include the initial investment cost (12%) and the complexity of vehicle conversion (10%). The cost of converting vehicles to use CNG, including the installation of CNG systems, may be prohibitively high for some vehicle owners. Additionally, the technical complexities involved in converting a vehicle's fuel system to accommodate CNG can be a deterrent, particularly for those who lack access to conversion services or expertise. Furthermore, fueling time and the short driving range of CNG vehicles, which affect 8% of owners, add to the inconvenience factor. Vehicles running on natural gas may require more frequent refueling due to their shorter range, making them less practical for longer journeys or in areas with fewer refueling stations.

Lack of awareness (3%) and the price of natural gas (5%) are less commonly cited concerns, but they still play a role. The low percentage of respondents concerned about awareness suggests that many vehicle owners are already familiar with CNG as a fuel option, though further education on its benefits may still be needed. Meanwhile, the relatively small concern over the price of natural gas could indicate that CNG is seen as an affordable alternative to conventional fuels, but pricing still matters for some consumers, especially if the cost of installing CNG systems is not offset by fuel savings

5. Discussion

The adoption of compressed natural gas (CNG) in the transport sector is closely tied to the interplay of various socioeconomic and infrastructural factors. One key element in driving the transition to CNG is education, as individuals with higher education are generally more knowledgeable about the environmental and economic benefits of using cleaner fuels. Educated individuals are better positioned to appreciate the long-term cost savings and environmental advantages associated with CNG, even when faced with higher initial investment costs (Ogunlowo *et al.*, 2015). As seen in other studies, awareness and understanding of new technologies are crucial in fostering acceptance and eventual adoption, especially in the context of promoting sustainable energy alternatives (IEA, 2022; Kitole *et al.*, 2024). Therefore, enhancing public knowledge and providing educational campaigns can significantly influence the rate of adoption, particularly in emerging markets where environmental concerns are becoming increasingly pressing.

In contrast, the age and condition of vehicles present a significant challenge to CNG adoption. Older vehicles may not be technically or economically viable for conversion to CNG, as retrofitting can be both complex and costly (Khan, 2017). This issue reflects a broader trend observed in markets where used cars dominate, such as Tanzania. Given the prevalence of second-hand vehicles in developing nations, the feasibility of transitioning to CNG is hindered unless supportive policies or financial incentives are introduced (Liu *et al.*, 2012; Utouh & Kitole, 2024). Policymakers must consider creating subsidies or offering financial assistance to help offset conversion costs for vehicle owners. These efforts can help to encourage broader adoption, as the financial burden of vehicle conversion is a major deterrent for many owners (Bishoge *et al.*, 2018).

Infrastructure limitations represent another critical obstacle to CNG adoption. A well-developed refueling infrastructure is essential for ensuring the convenience and reliability of using CNG. Without sufficient CNG refueling stations, vehicle owners may be reluctant to switch to natural gas due to concerns about accessibility (Ishengoma & Gabriel, 2021). This issue is not unique to Tanzania but is a common challenge in many countries transitioning to alternative fuels. A lack of infrastructure can severely undermine efforts to promote cleaner energy in transportation. Consequently, investment in CNG infrastructure must be prioritized to foster widespread adoption. The government and private sector must collaborate to expand refueling networks, which would reduce logistical challenges for vehicle owners and encourage the use of CNG as a viable alternative to traditional fuels (Gerutu & Greyson, 2023).

Furthermore, safety concerns continue to play a significant role in deterring the adoption of CNG. Although CNG is recognized as a safe fuel source, public perception often lags behind technological advancements. Concerns about the potential dangers associated with CNG usage, such as fears of gas leaks or explosions, can hinder its acceptance. Overcoming these concerns requires concerted efforts to improve public awareness and promote safety education regarding the use of CNG. Similar challenges have been observed in other energy transitions, where the public's initial hesitation is gradually overcome through increased visibility of the technology and consistent communication about its safety (BP, 2022). Strengthening public confidence in CNG's safety will be crucial to achieving broader adoption.

Lastly, financial considerations are always at the forefront of decisions regarding fuel adoption. While CNG is generally more cost-effective than gasoline or diesel in the long run, the initial investment required for vehicle conversion remains a barrier for many owners. As seen in other markets, the high upfront costs can outweigh the perceived long-term savings, particularly in low- and middle-income contexts (Igbojionu *et al.*, 2019). To address this, it is essential to develop supportive financial policies, such as tax incentives, subsidies, or low-interest loans, to help reduce the initial burden of CNG conversion (Guma, 2016). These measures could create a more financially accessible pathway for vehicle owners to make the switch, further bolstering the economic viability of CNG as a transportation fuel (Curran *et al.*, 2014). Promoting CNG as a cost-effective and environmentally friendly alternative requires a combination of education, infrastructure investment, and financial support to ensure its success in the broader energy transition (Kitole & Sesabo, 2024; Khan *et al.*, 2015)

6. Conclusion

The adoption of compressed natural gas (CNG) as an alternative fuel in the transport sector presents significant opportunities for reducing both environmental impact and fuel costs. However, the successful transition to CNG depends on overcoming several key challenges, including infrastructure limitations, financial barriers, and public perceptions about safety. Education plays a critical role in influencing the willingness of vehicle owners to adopt CNG, as greater awareness and understanding of its benefits can drive acceptance. Moreover, targeted policies that address the financial burden of vehicle conversion and expand the availability of refueling infrastructure are essential for supporting this transition.

The complexities associated with older vehicles and the initial costs of conversion continue to be significant barriers, particularly in markets dominated by used cars. Addressing these challenges will require concerted efforts from both policymakers and the private sector to develop financial incentives and support systems that make CNG adoption more accessible. Furthermore, public confidence in the safety and reliability of CNG must be strengthened through educational campaigns and transparent communication about the benefits and risks of the technology.

Ultimately, a multi-faceted approach that combines education, infrastructure development, and financial support is necessary to promote the widespread adoption of CNG. By addressing these challenges holistically, CNG can emerge as a viable and sustainable fuel alternative that contributes to cleaner energy use in the transportation sector, supporting broader efforts to mitigate environmental impacts and enhance energy security.

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