



A COMPARATIVE ANALYSIS OF LIQUEFIED PETROLEUM GAS (LPG) AND COMPRESSED NATURAL GAS (CNG) AS ALTERNATIVE FUELS FOR INTERNAL COMBUSTION ENGINES

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<https://doi.org/10.5281/zenodo.17928492>

https://njrer.org/download/a_comparative_analysis_of_liquefied_petroleum_gas.pdf

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ARTICLE INFORMATION

Article history:

Received 15 Jan., 2025

Revised 27 Jul., 2025

Accepted 18 Oct., 2025

Available online 30 Nov., 2025

Keywords:

Alternative fuels, LPG, CNG, combustion analysis, emissions, energy efficiency, internal combustion engine.

Abstract

The global call for cleaner and more economical fuels has renewed interest in alternative fuels such as Liquefied Petroleum Gas (LPG) and Compressed Natural Gas (CNG). This study presents a comprehensive experimental comparison of LPG, Petrol (Gasoline), and CNG as fuels for internal combustion engines, focusing on combustion rate, energy efficiency, emissions, and cost effectiveness. Results showed that Petrol recorded the fastest combustion time (32 min/kg), followed by LPG (75 min/kg) and CNG (97 min/kg). Energy analysis revealed that although Petrol produced the highest instantaneous energy (1.45 MJ/min), its Relative Efficiency Index (REI) was lowest (0.69). Conversely, CNG achieved the highest REI (1.82), demonstrating superior long-term efficiency. Environmental measurements showed that CNG emitted the lowest pollutants CO (0.9 ppm), NO (0.79 ppm), and NO₂ (0.48 ppm) with no detectable SO₂ or H₂S. Economically, CNG emerged as the most cost-effective fuel at ₦20.83 per MJ, followed by LPG (₦22.00/MJ) and Petrol (₦27.64/MJ). Overall, CNG stands out as the cleanest, most sustainable, and most economical fuel alternative evaluated.

1. INTRODUCTION

The transportation sector plays a vital role in today's global economy, but it also contributes significantly to environmental pollution because it depends heavily on fossil fuels like petrol and diesel (Smith & Taylor, 2023). Burning these fuels releases large amounts of greenhouse gases (GHGs) and harmful pollutants, which worsen air quality, accelerate climate change, and pose risks to public health (Johnson et al., 2022). These growing concerns have pushed many countries to explore cleaner and more sustainable fuel alternatives. Among the options being considered, Liquefied Petroleum Gas (LPG), Natural Gas (NG), and its compressed form, Compressed Natural Gas (CNG), stand out as promising candidates.

LPG made mainly of propane and butane is produced during petroleum refining and natural gas processing. It burns more cleanly than petrol and diesel, resulting in lower emissions of carbon monoxide, nitrogen oxides, and unburned hydrocarbons (Mishra et al., 2023). It also has a high octane rating, which can improve engine performance and prolong engine life (Okoro et al., 2022).

Natural gas, which is mostly methane, is another fuel that has gained global attention. When compressed into CNG, it can be used effectively in internal combustion engines that are designed or converted for gaseous fuels (Sadiq et al., 2023). Vehicles running on CNG tend to emit significantly fewer pollutants, and several studies have reported a 20–29% reduction in carbon dioxide emissions compared to petrol powered vehicles (Johnson & Smith, 2023). CNG's clean combustion also reduces engine wear and lowers maintenance costs, making it attractive from both environmental and economic perspectives (Adebola et al., 2024).

Around the world, the adoption of LPG, NG, and CNG varies widely. Factors such as government policies, public awareness, local fuel availability, and the presence of supporting infrastructure all play important roles. In Nigeria, interest in CNG has increased in recent years especially after the removal of fuel subsidies that caused a sharp rise in petrol prices. Government led conversion and awareness programmes have been introduced to encourage the use of CNG for transportation (Adejumo, 2023; Ibrahim, 2023). However, progress has been slow due to infrastructure gaps, the high cost of vehicle conversion, and limited public understanding of the benefits and safety of these fuels (Eze et al., 2023).

Switching to fuels like LPG and CNG can bring substantial economic and environmental benefits. These include reduced emissions, cleaner air, lower fuel and maintenance costs, and improved energy security through reduced dependence on imported petrol (Ahmed & Bello, 2022; Taylor et al., 2022). However, unlocking these benefits requires addressing challenges related to engine adaptation, storage technology, safety protocols, and the development of accessible refuelling stations (Brown & Davis, 2023; Olawale et al., 2024).

This study therefore provides a comprehensive comparison of LPG, NG, and CNG, focusing on their environmental performance, economic feasibility, infrastructure requirements, and overall suitability as alternative fuels for internal combustion engines. The goal is to support informed decision making and contribute to Nigeria's ongoing transition toward cleaner and more sustainable transportation options.

Despite global efforts to reduce the environmental impact of fossil fuels, petrol and diesel remain the dominant transportation fuels. Their combustion releases large quantities of greenhouse gases, driving climate change, air pollution, and ecological damage (Smith et al., 2023). The transport sector alone contributes roughly 24% of global CO₂ emissions, highlighting the urgent need for cleaner alternatives (IEA, 2022). At the same time, fluctuations in the price of petrol create economic uncertainty especially in developing countries that rely heavily on fuel imports (Adejumo et al., 2023).

Although alternative fuels such as LPG, NG, and CNG offer environmental and economic advantages, their adoption remains limited. Several factors contribute to this slow transition: insufficient refuelling infrastructure, the high cost of converting vehicles, limited public

awareness, and persistent doubts about the performance and reliability of vehicles running on these fuels (Eze & Johnson, 2023; Mishra et al., 2023).

In Nigeria, the removal of petrol subsidies has further intensified the need for cheaper, cleaner energy options. The resulting rise in fuel prices has made alternative fuels more attractive to both individuals and businesses (Ibrahim & Ahmed, 2023). However, the lack of strong policy support, inadequate infrastructure investment, and slow implementation of conversion initiatives have hindered widespread adoption of LPG, NG, and CNG (Okoro & Bello, 2024).

These challenges clearly show the need for a detailed assessment of alternative fuels to guide the transition to cleaner transportation. This study therefore compares LPG, NG, and CNG in terms of their environmental impact, performance characteristics, cost implications, and infrastructure demands. By identifying their strengths and limitations, the study aims to provide stakeholders policymakers, transport operators, and consumers with the information needed to make informed decisions and support Nigeria's shift toward cleaner, more sustainable fuel options.

2. MATERIALS AND METHODS

2.1 Engine Specifications

A single cylinder, four stroke generator capable of running on LPG, CNG, and Petrol was used. Conversion kits enabled switching between fuels.

2.2 Equipment

- Fuel flow meter
- Stopwatch
- Gas analyzer (for CO, NO, NO₂, SO₂, CH₄, H₂S)
- Pressurized LPG cylinder
- High pressure CNG cylinder (200–250 bar)

2.3 Experimental Procedure

Calibration of the generator was done to ensure it is in optimal working condition. Installation of the necessary conversion kits for both LPG and CNG usage was carried. 1 kg of each fuel was burned separately in the generator. Ambient temperature and pressure were recorded. Combustion time, emissions, and electricity generated were measured.

2.4 Data Analysis

The burning efficiency of each fuel was calculated based on the time required to burn 1 kg of fuel. Energy efficiency was analyzed by determining the amount of electricity generated per kilogram of fuel. Cost efficiency was evaluated by calculating the cost per kWh of electricity generated using the two fuels. The data was analyzed and presented in comparative tables and graphs for clarity.

- Combustion duration (min/kg)
- Energy rate (MJ/min)
- Relative Efficiency Index (REI)
- Emission concentrations (ppm)

- Cost per megajoule and cost per operating hour

3. RESULTS AND DISCUSSION

3.1 Determination of burning rate

Table 1. Combustion time for 1kg of fuel

| Fuel type | Combustion time | | | Combustion rate | % Combustion rate |
|--------------|-----------------|---------|-----------|-----------------|-------------------|
| | Start | End | Total | | |
| Petrol (1kg) | 9:30am | 10:02am | 32minutes | 0.031 | 3.125 |
| LPG (1kg) | 9:30am | 10:55am | 75minutes | 0.013 | 1.333 |
| CNG (1kg) | 9:30am | 11:07am | 97minutes | 0.010 | 1.031 |

Table 1 presents the combustion time and rate for 1 kg of petrol, LPG, and CNG when used in an internal combustion engine powered by a generator. Petrol burns completely within 32 minutes, showing the fastest combustion among the three fuels, with a combustion rate of 0.031 and a percentage combustion rate of 3.125%. LPG takes a longer time of 75 minutes to combust, with a lower combustion rate of 0.013 and a percentage rate of 1.333%. CNG has the longest combustion time at 97 minutes, with the slowest combustion rate of 0.010 and the lowest percentage combustion rate of 1.031%. These results indicate that petrol burns faster and is consumed more quickly, while CNG burns slower and lasts longer. Therefore, although petrol offers quicker energy release, CNG provides extended engine run time per kilogram, making it more efficient for prolonged use. This further supports the economic and energy-saving advantage of CNG over petrol and LPG.

3.2 Evaluation of energy efficiency of LPG, Petrol (Gasoline) and CNG

Table 3.2. Energy efficiency and relative efficiency index of LPG, Petrol (Gasoline) and CNG

| Fuel | Calorific Value (MJ/kg) | Time (min) | Energy per minute (MJ/min) | REI (relative units) |
|--------|-------------------------|------------|----------------------------|----------------------|
| Petrol | 46.4 | 32 | 1.45 | 0.69 |
| LPG | 50.0 | 75 | 0.67 | 1.49 |
| CNG | 53.6 | 97 | 0.55 | 1.82 |

The energy efficiency of a fuel can be assessed by how effectively it delivers energy over time during combustion. As presented in Table 3.2, petrol shows the highest energy per minute (1.45 MJ/min) due to its shorter combustion time, it is also the least efficient overall, as reflected in its lowest REI (0.69). This indicates rapid energy release but lower sustainability over time. On the other hand, Compressed Natural Gas (CNG) has the lowest energy per minute (0.55 MJ/min) but demonstrates the highest relative efficiency index (REI = 1.82). This means CNG burns more slowly and steadily, offering a more prolonged and efficient energy output over time. Its high calorific value (53.6 MJ/kg) and long combustion time (97 minutes) contribute to this performance. Liquefied Petroleum Gas (LPG) sits between Petrol and CNG in terms of energy efficiency. With an energy per minute of 0.67 MJ/min and a REI of 1.49, LPG provides a good balance between energy release rate and efficiency, making it a practical alternative in terms of consistent energy output and fuel economy. These findings are consistent with previous studies that show CNG and LPG offer higher thermal efficiency and better fuel economy than gasoline, particularly in applications requiring sustained operation (Agarwal et al., 2019; Choi & Song, 2020). The lower combustion temperature and cleaner burn of gaseous fuels also result in more efficient engine performance

and less energy loss (Okoro & Bello, 2024). Moreover, the slower combustion rate of CNG and LPG reduces thermal stress on engine components, leading to improved durability and reduced maintenance costs (Kumar et al., 2018). This further enhances their operational efficiency when used in internal combustion engines, especially under consistent load conditions.

3.3 Analysis of environmental impact of LPG, Petrol (Gasoline) and CNG

Table 3.3. Gas Analyzer Comparison for LPG, Petrol (Gasoline) and CNG

| S/N | GAS | LPG | GASOLINE | CNG |
|-----|------------------|-----------|-----------|-----------|
| 1. | O ₂ | 16.3% | 12.4% | 12.4% |
| 2. | CO | 4.1ppm | 2.1ppm | 0.9ppm |
| 3. | CO ₂ | 1.1% | 1.1% | 1.1% |
| 4. | NO | 1.2ppm | 1.0ppm | 0.79ppm |
| 5. | NO ₂ | 0.4ppm | 0.7ppm | 0.48ppm |
| 6. | SO ₂ | 29.2ppm | 0.0ppm | 0.0ppm |
| 7. | CH ₄ | 33.1% | 5.7% | 21.7% |
| 8. | H ₂ S | 75.6ppm | 0.0ppm | 0.0ppm |
| 9. | Pressure | -0.02inwc | -0.02inwc | -0.02inwc |

Table 3.3 presents the results of a gas analyzer comparison for LPG, petrol (gasoline), and CNG used in internal combustion engines. The oxygen (O₂) content is highest in LPG at 16.3%, compared to 12.4% for both petrol and CNG, indicating more excess air in the exhaust of LPG combustion. Carbon monoxide (CO) levels are highest in LPG at 4.1 ppm, lower in petrol at 2.1 ppm, and lowest in CNG at 0.9 ppm, showing that CNG produces the least amount of this toxic gas. Carbon dioxide (CO₂) levels are the same across all three fuels at 1.1%, suggesting similar combustion efficiency. Nitric oxide (NO) emissions are slightly higher in LPG at 1.2 ppm, compared to 1.0 ppm for petrol and 0.79 ppm for CNG, while nitrogen dioxide (NO₂) follows a similar pattern, with LPG at 0.4 ppm, petrol at 0.7 ppm, and CNG at 0.48 ppm. Sulfur dioxide (SO₂) and hydrogen sulfide (H₂S) are present only in LPG, with values of 29.2 ppm and 75.6 ppm respectively, and are completely absent in both petrol and CNG, indicating the presence of sulfur compounds in LPG. Methane (CH₄) content is highest in LPG at 33.1%, followed by CNG at 21.7%, and lowest in petrol at 5.7%. The pressure readings are identical across all three fuels at -0.02 inwc. Overall, CNG produces the least harmful emissions (CO, NO, NO₂, SO₂, H₂S) and is therefore the cleanest among the fuels tested, while LPG shows higher pollutant levels, particularly in CO, SO₂, H₂S, and CH₄.

3.4 Analysis of economic cost of LPG, Petrol (Gasoline) and CNG

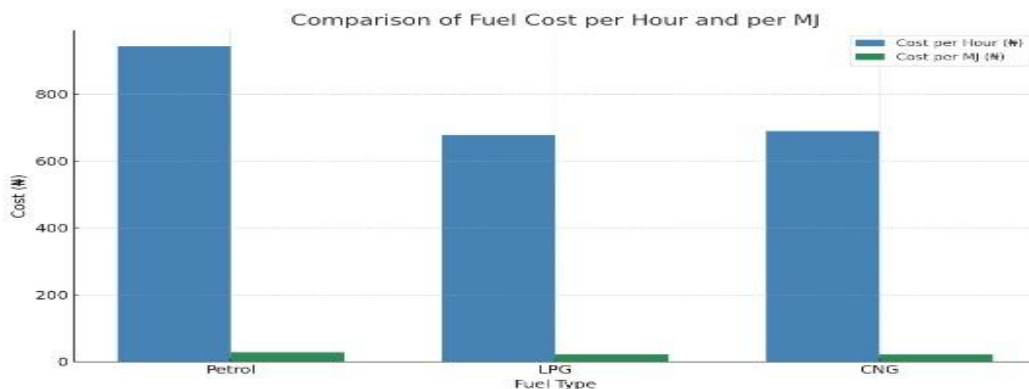


Figure 1. Economic cost analysis of various fuels used

Figure 1 depicts the economic cost analysis of various fuels used. CNG had the lowest cost per megajoule (₦20.83), making it the most economically efficient fuel. LPG followed with a cost of ₦22.00/MJ, while Petrol was the most expensive at ₦27.64/MJ. Similarly, operational cost per hour was highest for Petrol (₦943.01/hr) and lowest for LPG (₦679.01/hr), with CNG slightly higher at ₦689.66/hr.

4. COCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

This study conducted a comparative analysis of Liquefied Petroleum Gas (LPG), Petrol (Gasoline), and Compressed Natural Gas (CNG) as alternative fuels for internal combustion engines. The conclusions drawn from the findings are as follows:

- The combustion time results showed that Petrol had the fastest burning rate (32 minutes), followed by LPG (75 minutes) and CNG (97 minutes). This indicates that Petrol burns more rapidly, but CNG and LPG offer longer combustion durations per kilogram, which may be advantageous for extended engine operations.
- Although Petrol delivered the highest energy per minute (1.45 MJ/min), it had the lowest relative efficiency index (REI) of 0.69. In contrast, CNG and LPG had lower energy per minute (0.55 and 0.67 MJ/min, respectively) but demonstrated higher REI values of 1.82 for CNG and 1.49 for LPG, indicating superior efficiency in converting fuel energy over longer periods of operation.
- The gas emission analysis revealed that CNG produced the lowest levels of harmful emissions such as CO (0.9 ppm), NO (0.79 ppm), and NO₂ (0.48 ppm), making it the cleanest fuel among the three. Petrol had moderate emissions, while LPG showed higher values for CO (4.1 ppm), SO₂ (29.2 ppm), CH₄ (33.1%), and H₂S (75.6 ppm), indicating a higher environmental burden.
- In terms of cost-effectiveness, CNG was the most economical, with the lowest cost per MJ (₦20.83) and reasonable combustion time. LPG followed with a cost of ₦22.00 per MJ, while Petrol was the most expensive at ₦27.64 per MJ. Additionally, the cost per hour of operation was highest for Petrol (₦943.01/hr) compared to LPG (₦679.01/hr) and CNG (₦689.66/hr).

4.2 Recommendations

1. Government incentives for CNG infrastructure.
2. Expansion of LPG and CNG refueling stations.
3. Public awareness campaigns on safety and economic benefits.
4. Engine optimization for gaseous fuels.
5. Further research on long term engine durability.

Acknowledgement

The authors wish to acknowledge the funds provided for this research and publication by TETFund Centre of Excellence for Renewable Energy, Kaduna Polytechnic, Kaduna, Nigeria. The funds were provided by the Tertiary Education Trust Fund (TETFUND),

Nigeria, under the TETFUND Special Intervention for Establishment of Centre of Excellence (TETF/ES/DS&D/KADPOLY/COE /2021/VOL11).

Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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