A Study of LNG as Fuel for Vehicles- A Review

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Abstract

Fossil fuel is increasingly used in vehicles such as Buses and Trucks. Fossil fuels are also used in the manufacturing and energy sectors to generate electricity. The use of fossil fuels would increase Greenhouse gases, which will badly affect the environment. Many researchers have been proposing methods and schemes to protect the domain from the effect of greenhouse gases. This article has made an effort to study the use of LNG as fuel for vehicles such as Buses and Trucks. The main objective of this research work is (i) to explore the use of LNG as fuel for Buses and Trucks. (i) Operational viability (iii) Economic viability (iv) Safety and Security aspects. The article concludes that using LNG as fuel for vehicles such as Buses and Trucks will significantly reduce the emission of Greenhouse gases and thereby minimize the destruction of the environment.

Keywords
LNG Fuel, Fossil fuel, Greenhouse gases, Environmental sustenance, Carbon dioxide reduction, Fuel efficiency.

1. Introduction
Over the years, increased greenhouse gas emissions have been causing significant concern in many countries around the globe. Greenhouse gases (Figure 1) include CO2, SO2, CO, CH4, etc. Nearly 99% of Global transportation is carried out using Internal combustion (IC) engines (Felix Leach 2020). These IC engines use liquid fuels such as Petrol or Diesel. Environmental sustenance is the main goal set by the United Nations. Despite designing policies by the government to protect the environment from the emission of Greenhouse gases, many efforts are not giving significant results. With global warming is on the rise, tons of ice are getting melted, climatic variations including unexpected rainfall and violent floods, etc. The variation in climatic conditions also causes pandemics, significantly affecting society. These floods are so severe that they drive economic destruction and result in the loss of life. Thus, it is clear that fossil fuel is to be minimized for environmental sustenance.

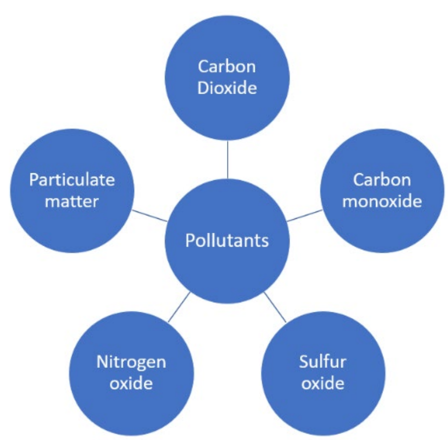

Figure 1. Pollutants and Particulate matter

1.1 Objectives
The main objective of the present research work is (i) to explore the use of LNG as fuel for Buses and Trucks. (i) Operational feasibility, (iii) Economic viability, (iv) study of the Safety and Security aspects. The article concludes

that using LNG as fuel for vehicles such as Buses and Trucks will significantly reduce the emission of Greenhouse gases and thereby minimize the destruction of the environment.

2. Methods

The current research work uses the following steps (Figure 2).

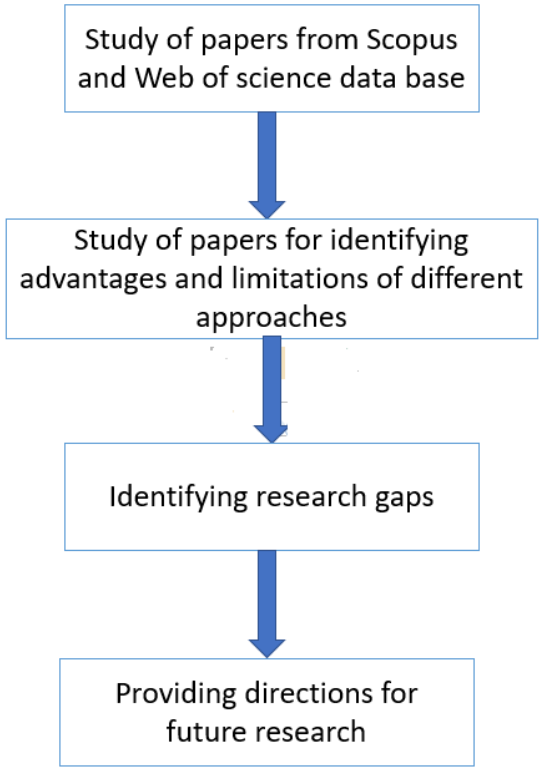

Figure 2. Steps in Research methodology

3. Literature Review

Many researchers have been working on studying transportation using Internal combustion engines. Nearly 99% of the world's vehicles use internal combustion engines (Felix et al., 2020). However, many alternate fuels such as Hydrogen, Biofuels, and Electric battery are being explored by researchers (Kalghatgi 2018, Senecal 2019). These alternate fuels (Figure 3) still have barriers to widespread applications. Till such time, dependency on fossil fuels continues. Fossil fuels are becoming more popular because of their very high energy density. They can also be stored and transported with ease from place to place. Research shows that about 95% of the energy required for transportation is provided by burning 60% of fossil fuels (World Energy Council 2020, OPEC 2013. ExxonMobil 2017). The electric-driven lightweight vehicles have the advantage that they emit fewer pollutants when compared to conventional fuels (Arteconi et al. 2013).

The primary powers that drive today's heavy-duty trucks are gasoline and Diesel. The commonly used natural gas is compressed natural gas (CNG) and liquified natural gas (LNG). Most light-duty vehicles are petroleum-based and use spark-ignition engines. The main problem with using IC Engines is that they emit greenhouse gases. Greenhouse gases include carbon dioxide, carbon monoxide, nitrogen oxides, and hydrocarbon. Many countries worldwide are exploring using hydrogen and other fuels for running IC engines. This is mainly motivated by the reducing emission of Greenhouse gases. A comprehensive life cycle analysis of alternate fuels is required before actually introducing these alternate fuels. Otherwise, there will be economic, social, and environmental consequences (Kalghatgi 2019). The batteries, for example, require materials, mining of which are very harmful to the life of human beings. According to one published report, there were 3.3 million battery-operated electric vehicles by 2018 (Statista 2018).

The usage of battery vehicles also requires establishing charging stations. This would demand huge investments. This may be difficult for many developing countries. This would also require governments to formulate policies and require effective implementation. With these many challenges, one researcher forecasted that even by 2040, about 90% of the energy needed for transportation would come from fossil fuels (BP Energy Outlook 2019). Another concern with these spark-ignition engines is nano-particle emission; these particles have dimensions lower than 100 nm. Diesel engines are based on compression ignition. Diesel fuel should have a high Cetane value. Also, many of these fuels have research octane numbers higher than 90. So that the combustion becomes easy. The main problem with Diesel engines is that they emit Nitrogen oxides and particulate matter. This particulate matter is very harmful to human beings. Current diesel engines are more efficient than petrol engines.

Table 1. The PM $_{2.5}$ emission and reduction of each scenario [Source: Zhao Q. et al. (2021)]

Scenarios	Plan	Introduction	Emissions in High-Temperature Season	Emissions in Low-Temperature Season	Annual Emissions	Annual Reduction	Avg. Reduction Rate
S1	-	Maintaining the status quo	895 t	1210 t	2106 t	-	-
S2	A	Promoting 15,000 China-V diesel HDTs	609 t	824 t	1434 t	672 t	31.9%
	B	Promoting 15,000 LNG HDTs	573 t	774 t	1345 t	761 t	36.0%
S3	A	Promoting 35,000 China-V diesel HDTs	455 t	615 t	1070 t	1036 t	49.2%
	B	Promoting 35,000 LNG HDTs	368 t	498 t	866 t	1240 t	58.8%
S4	A	Promoting 76,000 China-V diesel HDTs	217 t	293 t	510 t	1596 t	75.8%
	B	Promoting 76,000 LNG HDTs	30 t	40 t	70 t	2036 t	96.7%

Note: Reduction is the difference between each promoting scenarios and Scenario 1.

In the case of spark-ignition engines, high compression ratios and weak fuel mixtures would improve the efficiency of these engines. Fuel requirements for spark-ignition engines are discussed in detail in Kalghatgi (2017). Cetane number shows the autoignition quality of Diesel fuel. The fuels used in marine engines will have high sulfur content. When the research octane number is higher, the power will have a low Cetane number (Kalghatgi, 2005, Kalghatgi, 2014). Present-day engines will have better fuel efficiency, but the limitations are that they have high NO emissions.

The transport sector in India contributes Carbon emissions of 15.2% (Saurabh 2022). This shows the need for cleaner fuels. The authors have studied alternate fuels such as compressed natural gas (CNG) and Liquified Natural Gas (LNG) as fuel for vehicles based on internal combustion engines. The main limitation of CNG is that they have a very low energy density. They studied the physiochemical properties, storage requirements, ignition requirements, and safety requirements. The study also includes availability, accessibility, acceptability, and affordability. They have also studied fuels from both short-term and long-term perspectives. The investigation was concluded by identifying CNG and LNG as fuels for the passenger sector. LNG and Hydrogen fuels were recommended for the freight sector.

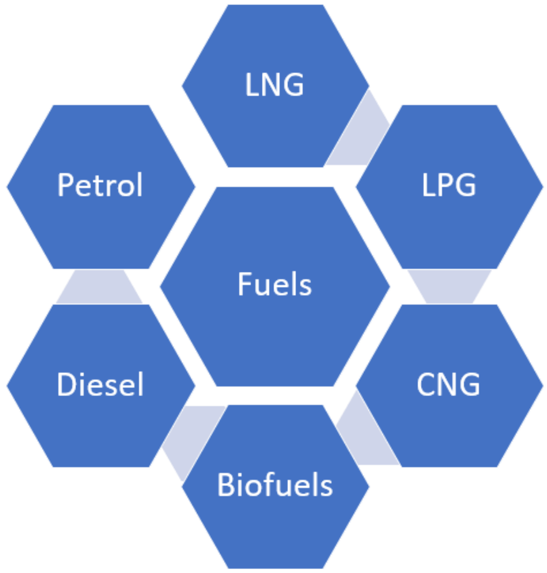

Figure 3. Types of fuels

According to a WHO report, particulate matter (PM_{10} and $PM_{2.5}$) is the most severe pollutant damaging the earth's environment. Hu et al. (2022) proposed a life cycle model to compare LNG and Diesel driven tractors in China. Their investigation showed that the LNG tractor-trailer consumed more energy and iron but less aluminum. The study also revealed that the LNG tractor-trailer emits less sulfur oxide, nitrogen oxide, and minor particulate matter. They also reported that the LNG tractor-trailer emits more greenhouse gases and carbon monoxide. Zhao et al. (2021) studied passenger or light-duty transportation in China. They stated that the transportation sector alone contributes to 29% of the total energy demand. They reiterated the high emission aspect of the transportation sector. They compared the performance of heavy-duty trucks using Diesel and LNG. They concluded that the NO emission had been reduced to 35.4% using LNG trucks. It was also observed that as the number of buses increased, the effect of NO reduction was even more significant. Researchers have identified the urgent need to control emissions in reducing air pollution in developing economies (Ramacher 2020, Kholod et al. 2016, Tischer et al. 2019, Dasgupta et al. 2021). The main advantages of using LNG are that they are available, less costly (Figure 4), and environmentally friendly (Wei et al. 2016).

Natural gas-driven vehicles have helped many cities worldwide reduce the emission of pollutants and thereby improving the air quality (Askin et al., 2015, Karavalakis et al., 2016). Literature reported that CNG and LNG buses were started functioning in 1999 and 2012, respectively. One research showed that LNG buses are most efficient than CNG buses because of their high energy density. Many LNG buses started working in China in 2015 (Dickens et al. 2016, Federal Transit Administration 2016). LNG-run buses are more economical than Diesel run buses (Zhao et al., 2021). LNG emissions are considerably lower than Diesel run vehicles (Yoon et al., 2013, Yoon et al., 2014). One research showed that the return on investment in LNG-driven vehicles would be one-third of the service life. This once again reiterates the fact that LNG vehicles are more economical. As of 2021, the ratio of LNG/Diesel prices in China was about 0.95 (Zhao et al. 2021). They also concluded that if LNG replaced all the heavy-duty vehicles in China, the total reduction in NO emission in China could be as high as 75%. In 2015, the USA had more buses run on LNG. One researcher reported that the size of the particle mass is tiny in the case of LNG-run buses (Housing and Construction Bureau of Shenzhen Municipality, 2017).

3.1 Scenario in China

3.1.1 LNG Security

In China, LNG was imported from many countries such as Qatar, Australia, Indonesia, Malaysia, Yemen, etc. The capacity of LNG receiving terminals in Shenzhen (China) is 16% of the whole country (Hao et al. 2016). Shenzhen (China) gets 40 billion m^3/year through the west-east gas line project (Zhao et al., 2021). They considered the following scenarios (Table 1 and Table 2).

Scenario 1(S1): Maintaining the status quo; Scenario 2(S2): Replacing 15000 Heavy-polluting HDTs; Scenario 3(S3): Replacing 35000 HDTs; Scenario 4(S4): Upgrading all HDTs to LNG.

3.1.2 LNG Fueling stations

There were 24 LNG Fueling stations in China in China (Housing and Construction Bureau of Shenzhen Municipality, 2017). Refilling of LNG take would take less time than that of a Diesel tank. This is because of the high pressure of the dispenser. China had constructed 13 LNG fueling stations in 2016 for serving a variety of vehicles (Housing and Construction Bureau of Shenzhen Municipality, 2017).

Table 2. NOx emission and reduction of each scenario [Source: Zhao Q. et al. (2021)]

Scenarios	Plan	Introduction	Emissions in High-Temperature Season	Emissions in Low-Temperature Season	Annual Emissions	Annual Reduction	Avg. Reduction Rate
S1	-	Maintaining the status quo	32,669 t	30,344 t	63,013 t	-	-
S2	A	Promoting 15,000 China-V diesel HDTs	29,627 t	27,518 t	57,133 t	5880 t	9.3%
	B	Promoting 15,000 LNG HDTs	27,352 t	25,406 t	52,747 t	10,266 t	16.3%
S3	A	Promoting 35,000 China-V diesel HDTs	25,996 t	24,146 t	50,078 t	12,935 t	20.4%
	B	Promoting 35,000 LNG HDTs	20,689 t	19,218 t	39,894 t	23,119 t	36.7%
S4	A	Promoting 76,000 China-V diesel HDTs	20,309 t	18,864 t	39,103 t	23,910 t	37.8%
	B	Promoting 76,000 LNG HDTs	8763 t	8140 t	16,903 t	46,110 t	73.2%

Note: Reduction is the difference between each promoting scenarios and Scenario 1.

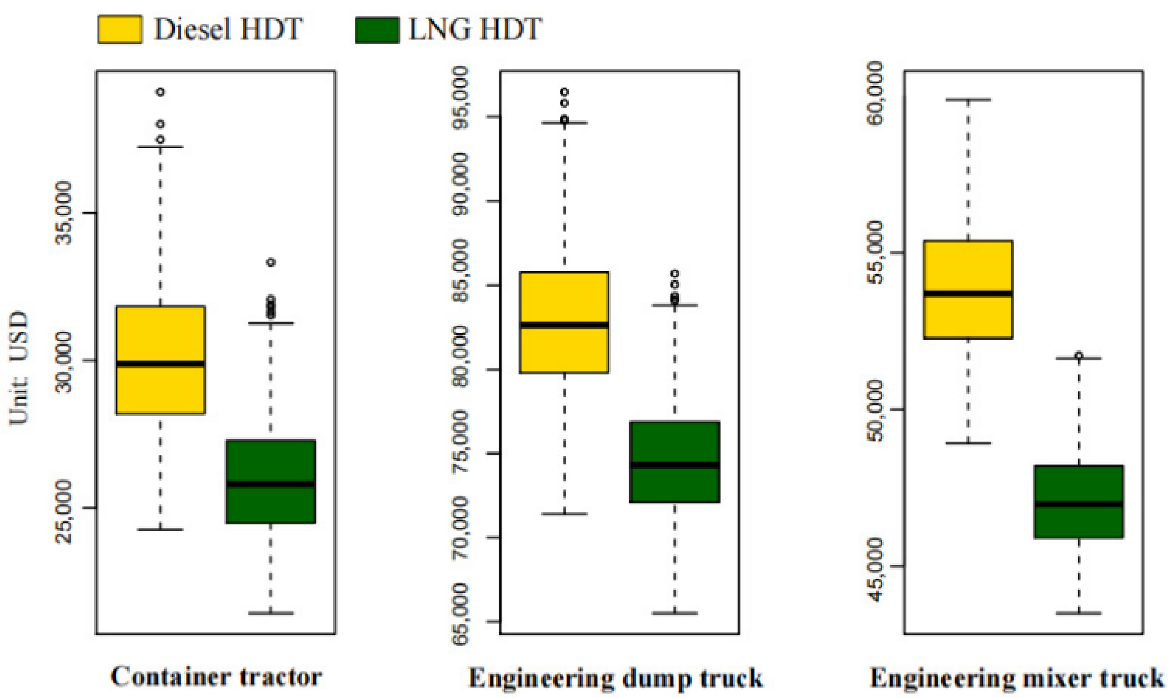

Figure 4. Box plot of annual costs of three types of Heavy-Duty Vehicles [Source: Zhao Q. et al. (2021)]

3.2 The scenario in European Union

In 2017, the European Commission designed the Strategic Transport Research and Innovation Agenda (STRIA) to implement Europe on the move strategy (European Commission. 2017, European Commission. 2021). European

Commission came out with alternative energy for transport (ALT). This article has made an effort to explore the status of research about ALT.

The main limitations of using CNG are less available space in vehicles (low energy density compared to Diesel), refueling time, and the availability of CNG stations in some regions (Khan et al. 2015). Not much research is done on the use of LPG and Bio-LPG fuels. Only seven projects worth 66.5 M Euros had been reported in the literature. Thus, the suitability of LPG and Bio-LPG as primary or alternate fuels is difficult to conclude. More research is required in assessing the suitability of LPG and Bio-LPG as fuel is needed. The main advantage is that conventional Petrol driven cars can run on LPG economically to reduce carbon emissions.

Bio-fuels are obtained from edible food crops such as sugar cane, palm oil, etc. Biofuels include biodiesel, vegetable oil, bioether, and solid fuels. Biofuels are also made from agricultural produce. The sustainability aspects of biofuel, including food vs. fuel, need further research (Mohr et al., 2013, Moriarty et al., 2019). Linares et al. (2013) and

Panoutsou et al. (2021) studied the difficulty of implementing biofuels in Europe.
The LNG production process involves four stages such as production, liquefaction, transportation, and regasification. The European Union has reported using different types of fluids, such as methane-based fuels, Liquified petroleum gas, and Biofuels.

Brynolf et al. (2014) studied the pollutants and emissions of LNG, methanol, Bi-methanol, and liquefied Bio-gas. They have learned that shifting from heavy fuel to LNG would result in reduced emissions of NO_x and SO_2. They also observed that CO_2 and CH_4 emissions would be the same as rich oil by using LNG.

Withers et al. (2014) have studied LNG's socio-economic and environmental impact as an aircraft fuel. They observed that fuel costs would be reduced to 14% using LNG as fuel. They have also observed that retrofit care must be exercised about CH4 leakage while using LNG. They found that LNG fared 12% better than conventional fuel about socioeconomic status. They stated that the above data would depend on the cost of fuel and that of retrofit. Methane-based fuels, which are more economical, are already available in the European market. These methane-based fuels have limited advantages over conventional fuels such as Petrol and Diesel. However, much research needs to be done as far as Methane-based fuel is concerned. Renewable fuels, on the other hand, have significant environment-related advantages. But, renewable fuels (e.g., Biofuels) are not popular in Europe due to a lack of infrastructure. Also, much research is expected from researchers in this direction.

3.3 The Scenario in India

In India, transportation contributes 13.2% of total CO_2 emissions as most vehicles (97%) use fossil fuels. This highlights the need to develop alternative fuels in India for reducing GHG emissions. This also highlights the importance of research on fuels for transportation in India. Vehicles can be classified into light-duty and heavy-duty. India stands fourth in the importing of LNG globally. In India, fuels such as compressed natural gas (CNG),. Liquified Natural Gas (LNG), Liquified Petroleum Gas (LPG), and Biofuels are being explored for the transportation sector. Research is still in its infancy. Much research is required from researchers to assess different types of fuels. The research should focus not only on operational feasibility but also on economic viability. Safety and security aspects as applied in the Indian scenario are to be studied in detail. India has been importing LNG from Australia, Algeria, Trinidad, Tobago and Russia, and Yemen; there is a massive demand for natural gas because of the availability of infrastructure regarding transmission and distribution and the resulting savings from the use of natural gas. Both power and fertilizer sectors consume more LNG. This may be as high as 75% of the total demand. The remaining 25% is consumed by domestic consumption, city vehicles, and other industries. According to one report, India would require nearly 25% of energy requirements met through natural gas by 2025. India is getting the new infrastructure in fueling stations, transmission, and distribution networks. Today, India has a regasification capacity of 30 mmtpa, and it might reach 55 mmtpa by 2025 (Report 2022). India has many R-LNG terminals located at Dahej (15 mmtpa), Hazira (7.5 mmtpa), (Gujarat); Kochi (5 mmtpa), (Kerala); Dhabol (5 mmtpa),(Maharashtra). India has been constructing new terminals to meet the increased demand. India has a gas transmission pipeline of about 16200 km, which may grow to 27000 km in 2025. The above paragraphs clearly show that there is a need for pursuing research in the area such as distribution of LNG, design of vehicles for running on LNG including fuel tank design, safety analysis of vehicles using LNG, Simulation of infrastructure requirements, infrastructure including the number of refueling stations required, the possibility of converting existing petrol or Diesel stations into LNG stations, Possibility of studying the use of duel fuel for transportation, fuel-mix for short term use, fuel-mix for the long term use, etc.

4. Conclusion and Future directions

Researchers have been studying using Liquified Petroleum Gas, Biofuels, Hydrogen, CNG, and LNG as fuel for the transportation of both light-duty and heavy-duty transport through trucks, buses, and other vehicles.

- LPG offers very few advantages when compared to conventional fuels. More research is required to assess the decarbonization of LPG and Bio-LPG fuels in the transportation sector. Whether LPG can be used as a primary fuel or alternate fuel is unknown. Very little research has been done about the use of LPG and Bio-LPG.
- Biofuels are environmentally friendly, but they are not economical compared to conventional fuels. Much research is required in this direction.
- LNG is economical and offers some reduction in greenhouse gas- common pollutants and particle emissions. The methane leakage issue needs to be addressed. But more research is required in this direction
- LNG as fuel is already tested in a few countries such as America, Canada, India, and China for LD and HD transportation.
- The demand for LNG in India, like in other parts of the world, is growing, and researchers have much scope for studying operational, economic, safety, and environmental aspects.
- India is emerging as a significant LNG market shortly. There is a massive demand for consumer-friendly regulatory authority for achieving long term goals,
- The main limitation of this paper is that only fuels that can be used in IC Engines are presented in this work. Electric vehicles are not considered.

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