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Review Paper

LPG-Fueled Vehicles: An Overview of Technology and Market Trend

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Abstract

This article presents an overview of the technology status and market trends of LPG-fueled vehicles through the literature approach to re-evaluate their future. In the review, it is discovered that LPG vehicles are globally increasing, though with a concentration in some countries. Of the 25 countries included in the World LPG Association (WLPGA) annual report 2018, Turkey, Poland, India, Ukraine, and Mexico are the countries with the best LPG vehicle trends in average of 23%. Meanwhile, Australia, Japan, South Korea, United Kingdom, the Netherlands, France, and Germany with a long history of implementing LPG as an alternative fuel has experienced a decline in the 2013-2017 period by 17%. This was allegedly due to the penetration of diesel-fueled vehicles over the last ten years. Moreover, developed countries experiencing decline have succeeded in developing electric-based vehicles such as Hybrid Electric Vehicle (HEV), Plug-in hybrid electric vehicle (PHEV), Battery Electric Vehicles (BEV), and Fuel Cell Electric Vehicles (FCEV) due to stringent demands for emission standards.

Keywords: LPG- fueled vehicles; LPG kits technology; Market trend

Abstrak

Artikel ini menyajikan ulasan tentang status teknologi dan tren pasar kendaraan berbahan bakar LPG melalui pendekatan literatur untuk mengevaluasi kembali masa depan mereka. Dalam ulasan ini, ditemukan bahwa kendaraan LPG meningkat secara global, meskipun terkonsentrasi di beberapa negara. Dari 25 negara yang termasuk dalam laporan tahunan World LPG Association (WLPGA) tahun 2018, Turki, Polandia, India, Ukraina, dan Meksiko adalah negara-negara dengan tren kendaraan LPG terbaik dengan rata-rata 23%. Sementara itu, Australia, Jepang, Korea Selatan, Inggris, Belanda, Prancis, dan Jerman yang memiliki sejarah panjang menerapkan LPG sebagai bahan bakar alternatif telah mengalami penurunan 17% selama periode 2013-2017. Ini diduga karena penetrasi kendaraan berbahan bakar diesel selama sepuluh tahun terakhir. Selain itu, negara maju yang mengalami penurunan telah berhasil mengembangkan kendaraan berbasis listrik seperti Hybrid Electric Vehicle (HEV), Plug-In Hybrid Electric Vehicle (PHEV), Battery Electric Vehicle (BEV), dan Fuel Cell Electric Vehicle (FCEV) karena tuntutan ketat pada standar emisi.

Kata-kata kunci: *Kendaraan berbahan bakar LPG; Teknologi kit LPG; Tren pasar*

1. Introduction

In addition to industrial and household consumption, world energy demand is increasing due to the rapid development of transportation. Over 60% of the total oil produced is consumed as a consequence of the growth in global population and urbanization. As a result, the transportation sector is the fourth most significant contributor of greenhouse gases (GHG) in the world with about 14% after electricity and heat production with 25%, agricultural, forestry, and land-use sector with 24%, and industrial sectors with 21% [1]. Moreover, in the United States, it is the highest contributor with 34%, higher than the industrial, residential, and commercial sectors with 27%, 21% z and 18%, respectively [2].

Currently, most vehicles are operated by gasoline and diesel as a primary fuel, and this is predicted to increase up to at least 2040 despite the continuous expansion of alternative fuels such as natural gas [3]. The increase in current fuel consumption is thought to decrease when electric vehicles are economically acceptable to the public with reliable infrastructure. As presented in **Figure 1**, the use of gasoline and diesel in 2018 reached more than 80 quadrillions Btu of the total energy consumption of around 115 quadrillions Btu. However, fossil fuels are very limited and unevenly distributed such that some countries can independently provide the quantity they need at low prices while most others depend on other countries due to lack of resources. Moreover, conventional fuels cause more pollution to the environment. Over the past decade, energy security, climate change, and increasing global energy demand have gradually started to attract public attention. Energy consumption in the transportation sector not only raises concerns about energy security and greenhouse gas (GHG) but also causes a decrease in air quality, especially in big cities, with consequent effects on human health [4].

To reduce dependence on oil and to develop sustainable transportation, many countries plan to replace conventional fuels with alternative ones in the future [5]. Biofuels are one of the considered options and they are very promising regarding sustainability due to the possibility of producing them from plants. However, large-scale production of biofuels such as bioethanol or biodiesel from plants and its derivatives conflicts with the availability of land to provide food [6]–[8]. Furthermore, the government is required to prepare reliable policies because biofuel production and implementation affect not only energy availability but also socio-economic and environmental balance. If it is not well guarded, there may also be deforestation and damage to living natural resources [9]–[12]. For example, the production and application of ethanol have been successfully conducted in Brazil with extensive land availability [13]. However, South Africa with sufficient land to produce biofuels-producing crops without risking food security already has policies but the development has not yet reached its potential [14].

1.1. Opportunities and challenges of using LPG in vehicles

Discussions about peak oil, availability, reserves, and oil prices are continuous due to their relevance. It is discovered that oil prices sometimes change not only because of demand but also due to regional or global issues such as economic, political and geopolitical factors [15].

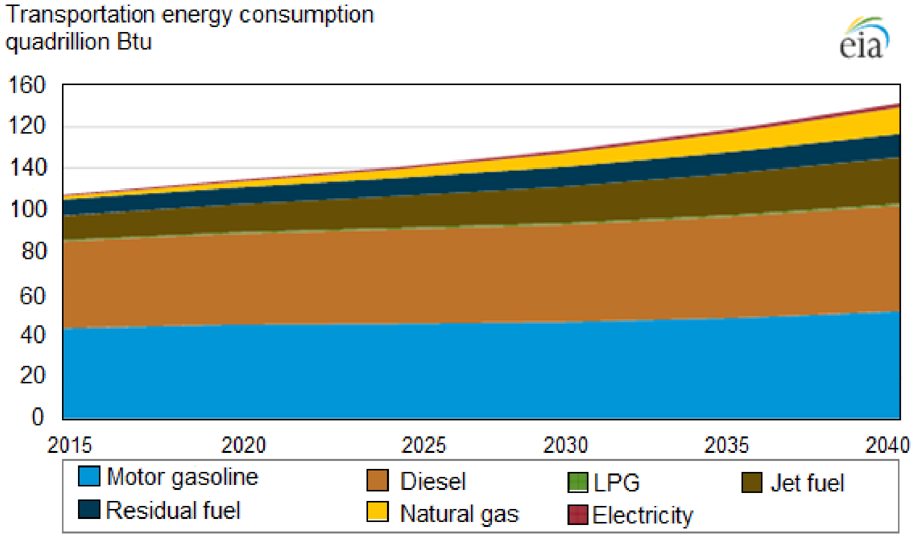

Figure 1. Projected fuel use for the transportation sector [3]

However, the rules on emissions and GHG are increasingly tightened, one of which is encouraging people to switch from fossil fuels to renewable fuel. This has led to the introduction of Electric Vehicles (EVs) and Fuel Cells (FCs) as promising clean technologies for the future. Technically, EVs and FCs are commercially available, but the high price of ownership makes it difficulty to be applicable in countries with low income per capita [16]. Despite the good intentions of the governments, providing infrastructure for these technologies to operate in large cities, it is still difficult due to its requirement of a broader area to interconnect the charging system [17], [18].

Limited stock, land-use competition, as well as underdeveloped technology, liquid biofuels, fuel cells, and hydrogen, are currently only able to replace fossil fuels to a very limited level when compared with Liquefied Petroleum Gas (LPG) [19]–[22]. Therefore, LPG is currently the most realistic alternative fuel to gasoline and diesel and for decades to come. Even though 60% of the global LPG is a refinery product, its lower carbon content compared to gasoline and diesel makes it an ideal option as a lower emission fuel. It is important to point out that this fuel has been used in vehicles for many years. For example, in the United States, its application in public transport started in 1910 in California and was standardized in 1963 with ASTM D-1835 by the Gas Processors Association (GPA) to provide uniform quality LPG [23]. The demand for conversion from gasoline to LPG increased sharply due to uncertain supply and high cost of oil because of the 1973 Arab Oil Embargo. In 1981, the number of LPG vehicles in the United States were reported to be nearly 250,000 and increased to almost 4 million over the next decade [24]. Moreover, based on the World LPG Association (WLPGA) survey, the number has globally reached more than 27 million in 2017 [25].

Over the years, LPG has become a popular choice in several countries due to generally lower pumping prices at fuel stations compared to gasoline and cheaper cost of supply with unsophisticated and low-risk infrastructure compared to Compressed Natural Gas (CNG) [26]. CNG applications involve more distribution equipment, including tubes and pipes to withstand high pressure (more than 200 bar) while the LPG pressure in the tank is only 10-12 bar [27]–[29]. The fuel stations only need to add LPG dispensers and tanks placed on the ground or underground with a special bracket. The promotion of this fuel as an alternative in some countries shows there is a serious commitment from the government with regards to fiscal and non-fiscal policies as well as research funding support. Therefore, through the use of comprehensive policies and continuous education to consumers, LPG can be used as a key element of energy planning in the road transportation sector to provide good socio-economic and environmental benefits on the medium term [30]–[32].

Majority of cars powered by LPG are converted from gasoline engines while some original equipment manufacturer (OEM) products can operate with both fuels. For cars converted from gasoline to LPG, some of these cars need minor adjustments to engine components, ignition settings, and electrical system connectivity. Some others use converter kits with compatibility depending on the type of engine based on specifications, volume, and suction ability. There are few challenges and problems attached to the use of LPG such as power loss and emissions [33]–[37]. Most of the researchers agreed that the power loss is due to volumetric efficiency [38]–[40]. The large volume difference between the liquid phase and the gas phase reduces the flow of fresh air in the Intake Manifold. However, the weakness in output power is compensated by the lower exhaust emissions from LPG vehicles than gasoline vehicles [30].

Furthermore, in spark ignition (SI) engines, LPG can be applied in fully-dedicated (mono fuel) or bi-fuel systems, where it is used alternately with gasoline fuels with the fuel selector switch placed on the dashboard for easy navigation by the drivers. For example, during the winter season, a driver can easily switch to gasoline due to the cold start problem associated with LPG properties and switch back to LPG after the engine has become stable. This bi-fuel system also makes it easier to travel in areas where LPG dispensers are not available than a fully-dedicated system. However, the weakness of this system includes an increase in the total weight of the vehicle due to the presence of an LPG tank as well as the requirement for multiple maintenances. In recent times, progress has been made on research directed towards solving the problems of high emissions during cold starts [41]–[43] as well as the use of lighter but stronger composite tanks to reduce the total weight [44].

Meanwhile, in diesel engines, LPG can be used in three ways; by replacing the engine with a gasoline engine, mixing it with diesel through the intake manifold to increase efficiency and reduce emissions, and modifying the engine. It is, however, important to state that the second method gets the most attention from researchers and it is commonly known as dual fuel. Several LPG mixtures have been tested to get the best performance and emissions without knocking symptoms. In the first stage, LPG and air were mixed and delivered to the cylinder like the Otto engine but in a lean mixture. At the end of the compression, a small amount of diesel is sprayed in a diffusion flame to start simultaneous combustion of a combination of premixed and diffusion flames [45]–[51].

Although the second method has the most attention, the third is the most popular method implemented due to the high octane number of LPG which guarantees its application in high compression pressures to obtain better thermal efficiency without the risk of knocking [52], [53]. Furthermore, diesel engines are modified to work like Otto engines, for example, fully-dedicated Heavy Duty Vehicle (HDV) has been successfully marketed in the United States and several European countries. In 2005, MAN company developed an environmentally friendly HDV based on LPG with a G 2876 DUH02 engine and the emissions produced were almost 50% below the EU-5 standard and also has the ability to reduce fuel consumption and CO_2 emissions by 14% compared to the previous engine (G 2866 DUH05). Other machines dedicated to LPG include the Ford V10 6.8L and Cummins Heavy-Duty LPG Engine B5.9 [54].

1.2. The reasons to convert vehicles to LPG

Conversion of vehicles from gasoline to LPG or buying OEM LPG cars is a popular trend in some countries due to the benefits of the fuel. Based on the WLPGA survey, there were 17.47 million LPG vehicles in 2011 and increased to 27.14 million in 2017, an increment of 9.67 million or 55% within six years. Moreover, Eric Hahn summarized ten technical, economical and environmental reasons encouraging people to be interested in converting their vehicles to LPG [55] that include reduced running costs, more competitive price, reduced maintenance costs, environmentally friendly, better for health, flexibility with dual fuel systems, no reduction in performance, availability, safety, and rapid payback.

2. Materials and Method

2.1. Data source

In this article, we review publications on LPG vehicle research and market trends. LPG vehicle research trends are obtained from various sources, but the main sources are publications obtained from reputable journals, which are complemented from proceedings, websites, and reports from authorized institutions, as presented in **Figure 2** [25], [33], [41], [56]–[74]. For LPG vehicle market trends, the annual report on Autogas Incentive Policies published by WLPGA was reviewed. The WLPGA Director was also contacted via email to obtain additional data and references.

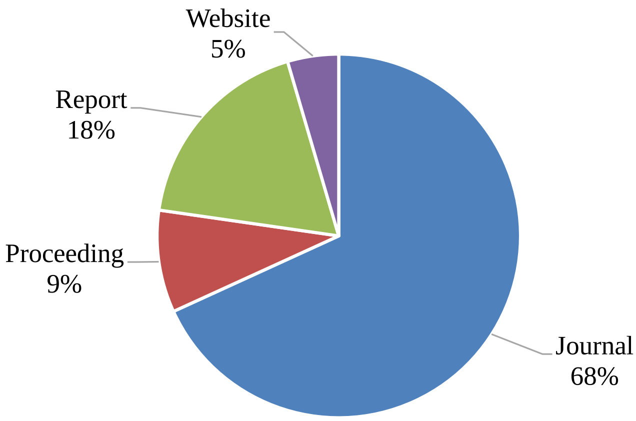

Figure 2. Data source

2.2. Assessing technology status

LPG fueled vehicles are basically gasoline-based. Therefore, the development of LPG kits technology with the gasoline fuel system was compared. Currently, the fuel system of gasoline engine reaches the Gasoline Direct Injection (GDI) developed from multi-point and mono-point injection systems which were preceded by a carburetor system as the most conventional way to mix fuel and air. Moreover, the development of LPG kits compatible with gasoline fuel system technology was examined and several publications were discussed to evaluate the potential and research problems for each of them. The types of LPG refueling stations and trends in the development of these vehicles marketed in several countries were also reviewed.

2.3. Assessing market trend

In this study, the results of the annual survey presented by WLPGA were used to evaluate the trend of LPG vehicles. Apparently, there is a different trend in the number of these vehicles and consumption for developed and developing countries. The existing graphs were converted to numerical data with WebPlotDigitizer [75] and the data obtained were grouped to differentiate groups of countries with respect to the growth in the number of LPG vehicles, decreases, and stagnation. This was followed by the analysis of the factors influencing them and their possibilities in the future.

3. Resuts and Discussion

3.1. Status of LPG kits technology

Up to the present moment, there are 5 types of kits used as supporting devices for LPG-fueled vehicles , namely Converter and Mixer (CM), Continuous Flow Injection (CFI), Vapor Phase Injection (VPI), The Liquid Phase Injection (LPI), and Liquid Phase Direct Injection (LPDI). Meanwhile, the gasoline fuel system developed from carburetors, mono-point injection systems, multi-point injection systems, and finally the gasoline direct injection system. Trends and comparisons of LPG and gasoline fuel systems on gasoline internal combustion engines are presented in **Figure 3** [71], [76].

Converter and Mixer (CM) fall under the first generation and the working principle of CM is recorded to be the same as a carburetor on a gasoline engine with the fuel and air mixed in the mixing chamber. Liquid LPG from the tank enters the vaporizer due to pressure in the tank without a fuel pump. The fuel evaporates in the vaporizer and enters the intake manifold through a mixer with the quantity based on the vacuum in the mixer venturi, without electronic control. In CM LPG kits, the engine performance and emissions are strongly influenced by vaporizer settings and mixer dimensions, as reported in the previous study [57]. CM LPG kit is still used on old vehicles (carburetor based) but it has been abandoned for a long time in developed countries due to emissions regulations.

Continuous Flow Injection (CFI) is slightly more advanced than CM generation and involves the addition of a microprocessor working based on signals from the engine management system sensors to improve the accuracy of LPG supply and reduce emissions. The working principle of CFI is almost the same as a mono point injection system on a gasoline engine which is called the K-Jetronic fuel system. This system allows electromechanical adjustments to replace settings based on engine vacuum and the large power losses in partial loads using CM can be reduced by it [58].

Vapor Phase Injection (VPI) is more sophisticated than the previous two generations and it is the most commonly applied system today [59]. It uses the evaporator to convert liquid LPG to vapor which is prevented from flowing back to the intake manifold and escaping to the exhaust during the overlapping valve by the electronically controlled injector. The injector opening time is controlled by an LPG control unit with the same working principle as the simultaneous MPFI on the gasoline engine, except that the fuel passing through the injector is gas. However, it is possible to improve the performance and emissions from the LPG engine but it is difficult to overcome the problem of volumetric efficiency due to the intake of air rations by the vapor in the manifold. Several studies have been conducted on this type of kits, from comparing performance to engineering for improved performance and emissions. The use of injection systems could significantly increase volumetric efficiency and brake power [33]. Another study was conducted by regulating LPG temperatures in the evaporator to improve performance and reduce emissions. Some of the

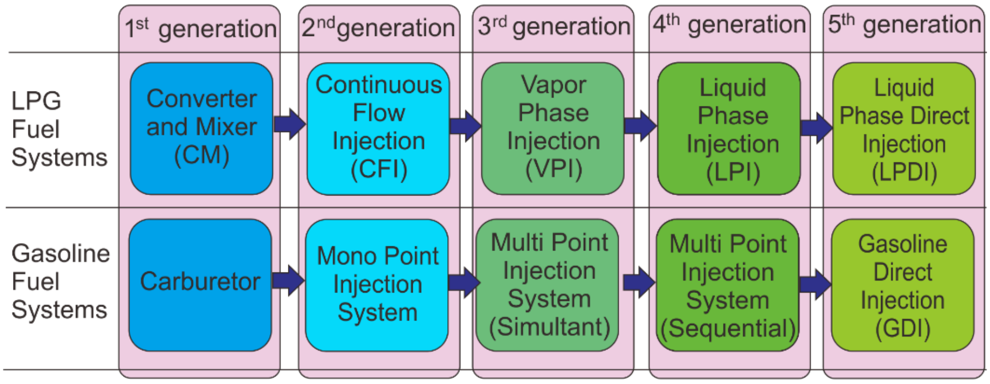

Figure 3. Step by step evolution on gasoline and LPG fuel delivery

engine coolants circulating in the evaporator are regulated by the PID controller [60]. Meanwhile, another study was conducted by mixing LPG with gasoline in certain compositions to get the best performance on Multi Point Fuel Injection (MPFI) engines [61]. Because it has been regulated electronically, LPG flow in the VPI can be further regulated based on vehicle dynamics, such as during deceleration and when driving down-way. LPG flow can be cut off or reduced for fuel savings under certain conditions [62], [63].

The Liquid Phase Injection (LPI) is more sophisticated than the VPI and this system allows the elimination of problems related to volumetric efficiency by utilizing liquid LPG properties. In LPI kits, the role of the vaporizer is replaced by electronically controlled injectors consisting of electronic switches with measuring devices, Electronic Control Unit (ECU), and sensors for engine coolant temperature, as well as LPG temperature and pressure. All information from the sensors installed in the kits and engines is supplied to the ECU to control injection timing. Sophisticated controls allow the injector on LPI to work sequentially, and the liquid LPG is pumped to the fuel rail like in the gasoline engine MPFI. Moreover, this fuel evaporates after being injected to cool the air in the intake manifold to increase air density. In LPI kits, the LPG temperature in the fuel rail can be precisely controlled to obtain optimal power and emissions [64]. Up to now, LPI kits are still being developed by producers based on the latest research information to achieve better fuel, power, and emission economy [59], [65], [66].

Finally, the Liquid Phase Direct Injection (LPDI) is the most sophisticated generation. It involves the supply of LPG tank directly from the pump through the use of a high-pressure fuel pump into the injector installed in the combustion chamber, like a Gasoline Direct Injection (GDI) system in a gasoline engine. One of the challenges in developing LPDI is creating the injector with the ability to withstand high dynamic temperatures. Moreover, instantly after being injected, LPG evaporates to cool the air during the compression stage and it is also possible to support the engines working with this system with a supercharger or turbocharger to increase thermal efficiency. With high pressure, the injection duration is generally shorter and more complex, requiring a reliable and capable electronic system to control the engine at high speeds. Several study reports related to LPDI found challenges of developing and implementing more complex ones [41],[67]–[70]. However, due to the uniqueness of fuel control management for each engine, LPDI is not universally developed like the previous generation. Therefore, LPG vehicles with LPDI are usually available as OEM products, not conversion products.

3.2. *Typical LPG filling stations*

LPG filling stations are generally integrated with automotive liquid refuelings such as gasoline, diesel, biodiesel, and biogasoline. However, the typical tanks and pumps used are different because of several construction methods employed in these stations. Therefore, an LPG station may be an additional facility integrated into previous fuel stations and does not require a compressor chamber as in CNG stations. The main equipment for LPG filling stations includes LPG vessels, pump sets, dispensers, valves, transfer lines for the fuel, and return lines for liquid LPG and vapor. Currently, there are three types of LPG filling infrastructure, and they include; (a) Above-ground tank installation, (b)

Lifts on underground tank installation, and (c) Submersible on underground tank installation, as presented in **Figure 4**. Among the three types, above-ground tank installation is a type that can be applied quickly to an existing fuel station as an additional facility, without digging the soil to place the tank.

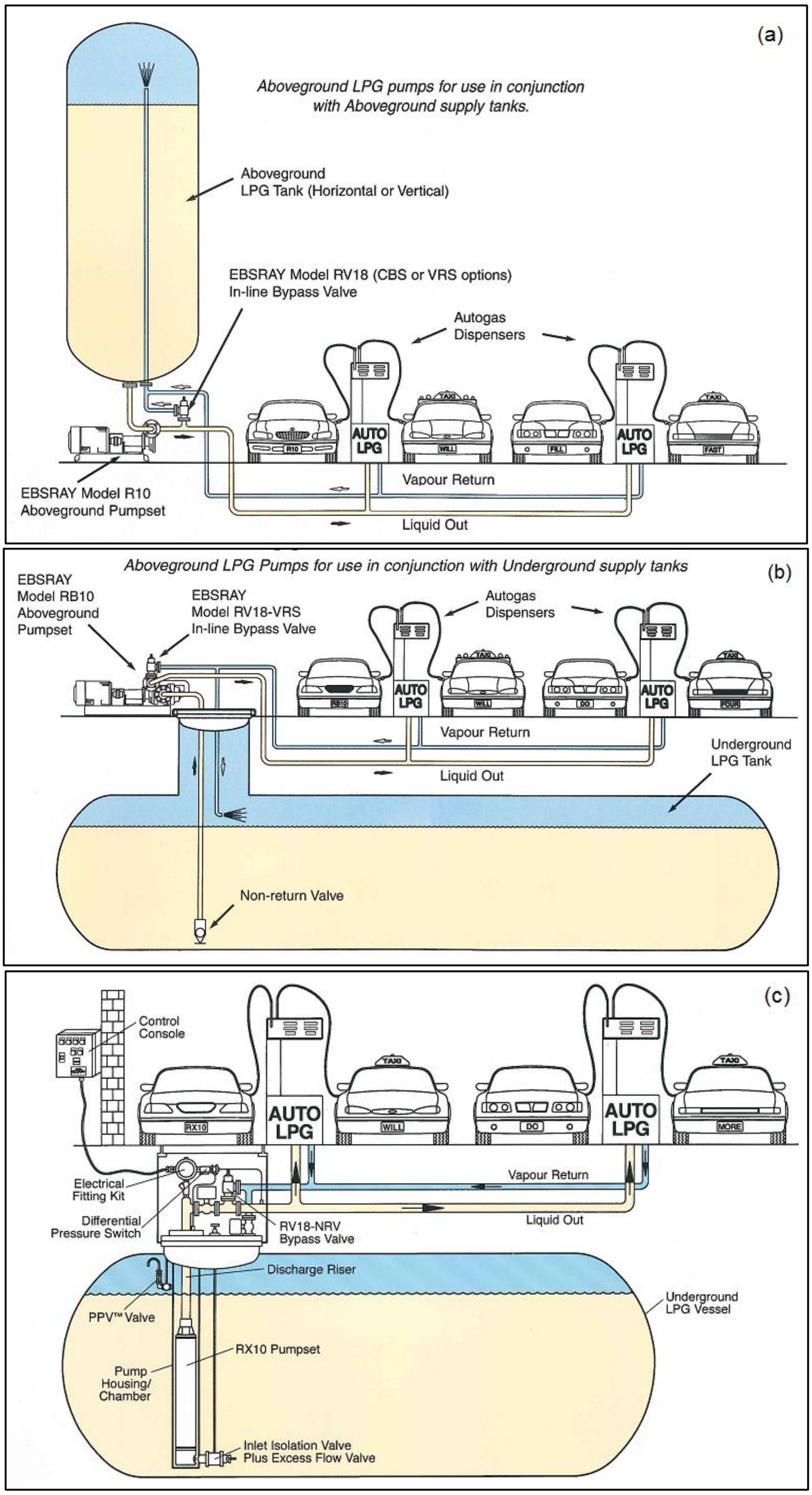

Figure 4. Typical LPG installation in refueling site: (a) Above-ground, (b) Lifts on the underground, and (c) Submersible on underground [71]

3.3. Recent LPG fueled vehicle

In 2018, WLPGA reported at least 136 new vehicle types from 45 car manufacturers producing vehicles with LPG fuel as their OEM products marketed in Europe, Asia, and the United States [56]. Of these, the passenger car is the most produced with 65.4% followed by trucks and buses with 12.5% and 4.4%, respectively. In Europe, they are used as Light-Duty Vehicles and they include passenger cars and vans/wagons with engine capacities ranging between 0.9 and 2.5 liters. In Asia (South Korea, Japan, and India) the characteristics are similar to those in Europe except for Bajaj three-wheelers with 200cc. Meanwhile, in the United States, they are widely used as High Duty Vehicles with engine capacities of 2.5 to 8.8 liters and characterized with large capacity engines, even for passenger and private cars operating daily. Furthermore, almost all the LPG vehicles in Europe are produced to use bi-fuel systems, while in Asia and the United States, there are bi-fuel or mono LPG (fully- dedicated) options. A more sophisticated option is observed in Asia with Toyota JPN Taxi produced as a hybrid vehicle. Some statistical data on LPG vehicles based on WLPGA data are presented in **Figure 5**.

3.4. Market trend

Although the total number of LPG vehicles in the world is reported by WLPGA to be increasing, in reality, this does not apply to all countries promoting the use of LPG as an alternative fuel. The analysis was conducted in 25 countries with the largest LPG consumption rating based on the WLPGA survey and 11 countries were found to be growing consistently over the past 5 years, 9 declined, and the rest tended to stagnate and fluctuate. However, 5 out of the previously mentioned 11 countries experienced significant growth, include Turkey, Poland, India, Ukraine, and Mexico while the remaining 6 including Bulgaria, United States, China, Portugal, Canada, and Spain seemed slow, as shown in **Figure 6**.

In Turkey, the massive growth of these vehicles started with a low tax policy for LPG as a household fuel which later penetrated the automotive sector [72]. Currently, although the price of LPG in Turkey is 72% and 82% compared to gasoline and diesel respectively, the growth of the vehicles remains high due to the relatively low conversion costs of around $600 for good quality. In Poland, LPG consumption reaches 10% of the total need for road transportation and government policies regarding excise taxes on gasoline and diesel have proven successful in promoting LPG fuel as an alternative [73]. Therefore, the price of LPG at the refueling site in 2017 was only 45% of gasoline and 47% of diesel.

In India, around 7% of all vehicles including three-wheelers on the road run with LPG. Major manufacturers such as Bajaj Auto, Maruti Suzuki, Tata Motors, General Motors, and Hyundai have now completed LPG kits as OEMs, making 65% of new vehicle registrations already equipped with both fully- dedicated and bi-fuel systems. The government has an active role in promoting LPG for vehicles, and the most important thing is related to tax exemptions. The price of LPG per liter in India is very competitive, being only 52% of gasoline and 63% of diesel. Similar conditions were also observed in Ukraine and Mexico, where the government's role in LPG taxes is the key to success in promoting LPG as a cleaner alternative fuel. In Ukraine, the price per liter is only 52% of gasoline and 47% of diesel. Meanwhile, in Mexico, it is 50% and 53% of gasoline and diesel, respectively [25].

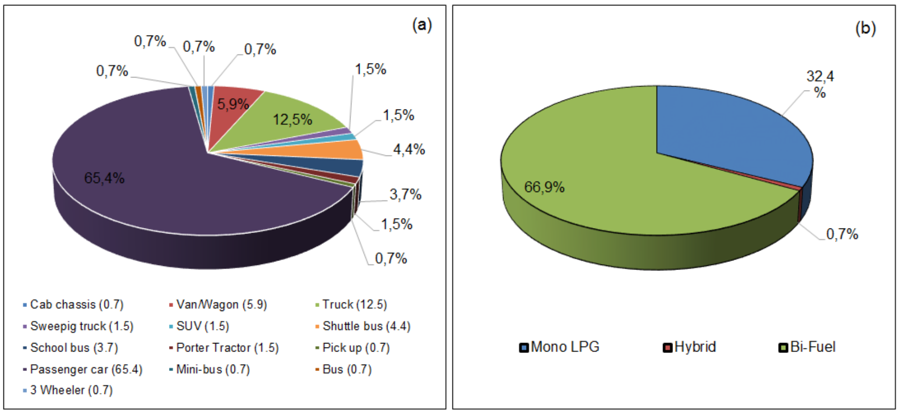

Figure 5. Statistical data of LPG vehicle: (a) classification based on vehicle type and (b) based on the fuel system

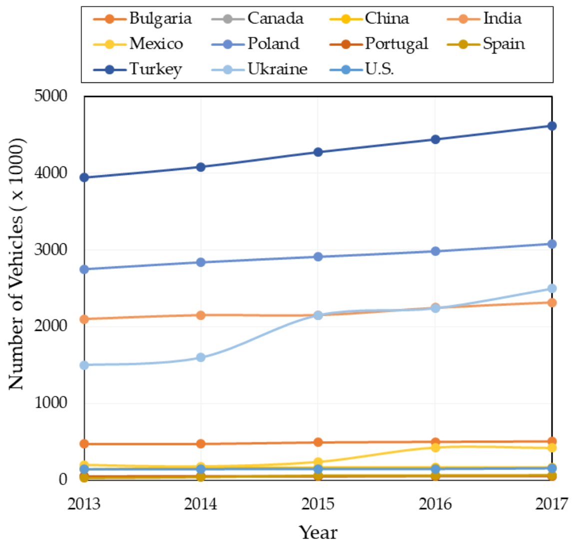

Figure 6. Trend (growth) of LPG vehicles in the selected countries

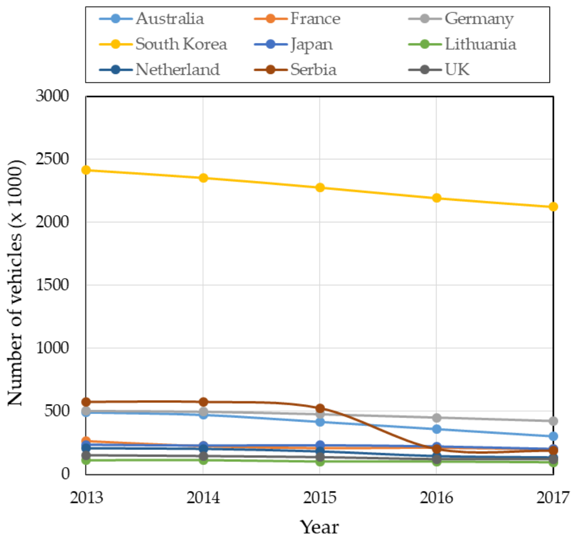

Figure 7. Trend (decline) of LPG vehicles in the selected countries

In China, the promotion of LPG for vehicles started with the concern of the local government as observed in Hong Kong and Guangzhou on the issue of air pollution even though the diffusion of LPG vehicles in the country was initially relatively low [74]. However, the small growth recorded in the use of the vehicles is due to the relatively low price of LPG compared to conventional fuels, which is 58% of gasoline and 79% of diesel. In the United States, although in the last 5 years there has been growth in LPG-fueled vehicles, the rate is too small when compared to conventional fuel consumption. This is due to the less competitiveness in LPG prices despite the conversion incentives provided by the government.

The contrary was observed in Japan, South Korea, and Australia, which are countries with a long history of using LPG for vehicles besides the Netherlands, the United Kingdom, Germany, and France. In the last five years, the number of LPG vehicles in Japan, South Korea, and Australia has decreased significantly as shown in Figure 7. This was alleged to be due to the penetration of diesel vehicles in the last 10 years [25]. Furthermore, developed countries that have experienced a decline in the number of LPG vehicles have succeeded in developing electric-based vehicles, such as such as Hybrid Electric Vehicle (HEV), Plug-in hybrid electric vehicle (PHEV), Battery Electric Vehicles (BEV), and Fuel Cell Electric Vehicles (FCEV) due to stringent emission standards [77]–[82].

4. Conclusion

This review showed the technological trend of the LPG fuel system to be following the gasoline fuel system. As observed, there are similarities in the working systems of the mixer and carburetor, the vapor phase injection and multi-point injection on gasoline, and finally, the liquid phase injection and direct injection system. Currently, LPI is most widely used to cover weaknesses in CM and VPI and it is reported to have good performance for power and emissions. Meanwhile, LPDI which is equivalent to GDI is still being developed by producers due to the challenges of high temperatures in the combustion chamber and the uniqueness of the control system.

The total number of LPG vehicles in the world is increasing and car manufacturers are marketing their products to several countries as OEM products, although each country has characteristics in the development of LPG vehicles, as passenger vehicles and as Heavy-Duty Vehicles (HDV). In Europe, LPG is used for Light-Duty Vehicles with engine capacities ranging from 0.9 and 2.5 liters. In Asia, such as South Korea, Japan, and India, the use of LPG for vehicles is similar to in Europe, except for three-wheeled Bajaj with an engine capacity of 200 cc. Different characteristics occur in the United States, where LPG is widely used for High Duty Vehicles with engine capacity of 2.5 to 8.8 liters, even for passenger and private cars.

In terms of infrastructure at the gas station, there are three types of filling stations, include above-ground systems, lifts on the underground, and submersible on the underground. Among the three types, above-ground tank installation is a type that can be applied quickly to an existing fuel station as an additional facility, without digging the soil to place the tank.

In terms of market trends, LPG vehicles were found to be growing effectively in developing countries but tend to decline in developed ones. In some developing countries, as reported by WLPGA, tax incentives and fuel price controls by the government are a strong driving factor for consumers to switch from gasoline to LPG. Significant price differences between LPG and gasoline encourage vehicle owners to convert their vehicles because of the short payback period and can be estimated to cover conversion costs. The reverse phenomenon occurs in developed countries that have long experience implementing LPG as an alternative to gasoline, such as Japan, South Korea, Australia, the Netherlands, the United Kingdom, Germany, and France. They succeeded in implementing electric based vehicles, such as HEV, PHEV, BEV and FCEV due to strict emission standards. As an implication, LPG vehicles have gradually declined over the past 5 years.

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information is available for this paper.

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