Bibliometric Analysis of Research on LPG Fuelled Internal Combustion Engines From 2001 to 2018

Byron Medina Delgado
Engineering Faculty
Universidad Francisco de Paula Santander, Cúcuta, Norte de Santander, Colombia
Email- byronmedina@ufps.edu.co

Carlos Acevedo Peñaloza
Engineering Faculty
Universidad Francisco de Paula Santander, Cúcuta, Norte de Santander, Colombia
Email- carloshumbertoap@ufps.edu.co

Gustavo Guerrero Gómez
Engineering Faculty
Universidad Francisco de Paula Santander Ocaña, Ocaña, Norte de Santander, Colombia
Email- gguerrerog@ufpso.edu.co

Abstract- This work shows a Bibliometric study of research carried out on internal combustion engines powered by liquefied petroleum gas - LPG, between 2001 and 2018. Currently, the need to replace traditional diesel and gasoline fuels is recognized. Due to its environmental effects, LPG has been one of the alternatives for substitution, given its caloric power similar to gasoline and for reducing emissions such as CO_2 or NO_X. To develop the research, the Web of Science platform was used, a server specialized in scientific information and was later analyzed with the Hiscite program, to finally determine the behavior of the bibliometric parameters. Internationally, it was determined that countries such as South Korea, India, Turkey and Italy, lead worldwide research on the subject, with Korea Institute Machinery & Materials, as the institution with the most publications produced and among the most important authors, Myung CL and Park S, both of Korean origin. Currently, Colombia is trying to implement this technology, there are government efforts and industrial associations interested in adding this type of energy to the vehicle sector.To carry out a study of the research on LPG in internal combustion engines carried out between 2001 and 2018.

Keywords – LPG, Combustion, Engine, Bibliometric, analysis

I. INTRODUCTION

Means of transport have always played a major role in human society, which has led researchers to direct their studies towards this subject [1]–[4]. Nowadays, given the great distances that man usually has to travel, it is necessary to have reliable, safe, efficient, economical and inclusive transport systems. The transport sector is also characterised by the high demand for energy, generally fossil fuels, especially in developing countries, where there are no major industries.

Based on the current need to implement energy resources with less or zero impact on the environment [5]–[8], or more environmentally friendly technologies to transition to the widespread use of clean energy such as transportation by electric cars [9]–[11] or hydrogen [12]–[14], but while this is happening, it is necessary to have substitutes for the traditional and more harmful diesel or gasoline systems [15]. An adequate substitute for these is the implementation of systems based on Liquefied Petroleum Gas or LPG, which have been tested in several countries, even many where they are not characteristic oil producers [16]–[18]. Another advantage of the inclusion of LPG or autogas, as it is known worldwide, is the diversification of the energy basket, where the chain of fuels for

vehicle use is reinforced, strengthening, as it does not depend on traditional fuels such as gasoline or diesel [19], [20]. LPG is basically a sub-product of the production of the oil and gas industry worldwide, which at environmental conditions is in liquid phase, which is basically made up of propane (C_3H_8) and butane (C_4H_{10}) [21].

Based on international experiences such as Italy, Turkey, Poland, Spain, Australia, South Korea, China, Iran, Mexico, Chile and other countries, where Autogas is a reality, of common use at the same level as gasoline [22]–[24]. Currently, around the world it is positioned as one of the most widely used alternative fuels, with a presence in nearly 63 countries, with a consumption that exceeds 21.6 million tons (675,000 bbl/day), equivalent to 8.2% of the world consumption of LPG, generated by more than 17 million vehicles, served by almost 54,000 service stations [25]. Research worldwide is currently focusing on determining the best operating conditions for LPG fuel blends, the most favourable LPG air blends and the emissions produced by LPG [26]–[29].

In Colombia there has been much debate on the subject, and many governmental and non-governmental organizations are currently working to make the use of Autogas viable and legal in Colombia [30]–[33]. As is the case of Resolution 40577 of 2016 of the Ministry of Mines and Energy [34], which regulates the use of LPG in vehicle use, however, at the moment there is a lack of definition of technical aspects, which based on this resolution the Ministry of Mines and Energy has only provided that all interested parties in the matter, carry out pilot tests to determine the operational parameters of the engines based on LPG. At the moment there is a lack of definition of aspects, technical aspects of conversions, commercial issues, LPG supply, etc. In conclusion, the penetration of these technologies is subject to economic, environmental, infrastructure, and gas reserve availability factors. The challenges to implement in Colombia technologies based on liquefied petroleum gas in the transport sector range from a behavioural change in the vehicle sector, through a restructuring in the supply of vehicles or engines with dedicated technologies, to the expansion of infrastructure throughout the national territory.

As a general framework, this work is aimed at determining the behavior of bibliometric indicators by analyzing the metadata concerning the topic, being this a method widely used to have a clear view of the research carried out on various topics [35]–[37]. This method will be applied for research on internal combustion engines operated on liquefied petroleum gas, to determine global trends in technologies related to the subject, with a view to a future implementation of this energy for vehicle use in Colombia.

.II. Methodology

To perform this bibliometric analysis, the data to be studied were obtained through the Web Of Science search engine. Liquefied Petroleum Gas Combustion Engine", "LPG Ignition Engine", "LPG Vehicle Fuel" and "Autogas" were used as keywords for the data acquisition. In addition, this search was conducted over a 16-year period (2001-2018), resulting in 172 records, almost entirely consisting of scientific articles, in addition to a few reviews and conference articles. After obtaining all this data, the information was analyzed in the Histcite program to finally determine the behavior of the bibliometric parameters.

The analysis of the indicators by country, author, journal, number of citations, types of documents, languages, categories, topics, research organizations and titles was carried out. Figures and tables were made according to more important indicators, which facilitated accurate and correct analysis of the data.

In terms of languages, we searched for the language in which it was most published. In addition, the years in which it was most published and which countries contributed the most were reviewed. On the other hand, it was reviewed which institution presented the greatest number of records in terms of publications and in the same way with the journals and authors.

III. Results and discussion

Below are the results of the analysis of the bibliographic database obtained, determining the most relevant aspects in order to characterize it, for which aspects such as language, country of origin, research institutions, the most referenced articles, publication journals, among others were verified.

3.1. Language

Of the total of 172 files found, it was determined that 97% was written in English being the language with the most articles reported on LPG as fuel in engines, then we found 3 articles in Turkish language, in addition to Korean, Polish and Russian, all with 1 article, less than 1%. Demonstrating the importance of the English language as a universal language of exchange in relation to scientific production.

3.2 Yearly Publication

In **Error! Reference source not found.**, we find the annual frequency of scientific production for the period 2001 to 2018, with a closing date of October 2018. Although there have been partial declines in the frequency of publications over the past few years, it can be said that there has been an increase in publications on the subject.

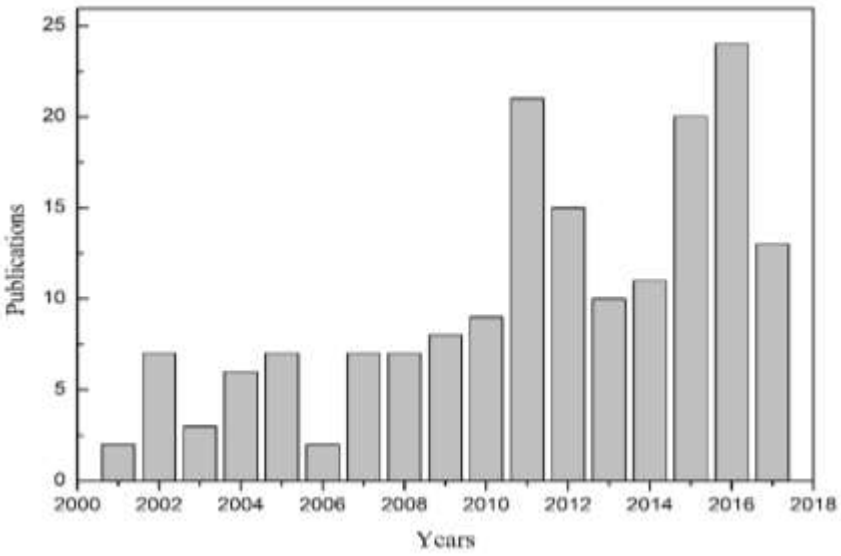

Figure 1. Scientific Production for the Period 2001 to 2017.

3.3 Publications by Country

A total of 28 countries contributed to the generation of the total number of publications, the number of publications for a particular country being an indicator of the scientific power of that country in a specific discipline or topic. In this case, South Korea is in first place with 25% of the total number of publications; Turkey (14%), India (13%) and China (11%) are also in second, third and fourth place respectively, these details are found in **Error! Reference source not found.**.

In addition, **Error! Reference source not found.** shows the number of citations made to articles from a given country, indicating the impact of publications among scientific circles and the quality of the scientific production of this country on that specific topic. For the analysis, the TLCS (Total local citation Score) and TGCS (Total global citation Score) indicators were used. The FTAA shows the number of citations with respect to the analysis database, in this case the 172 records. Likewise, TGCS indicates citations with respect to the total number of articles in the Web of Science database. From the data obtained, we observe that South Korea, in addition to being the country with the highest number of publications, is also the country with the highest number of references, as well as the countries in the following 5 positions.

In the same way, an analysis was made of the number of citations among the number of publications by country, FTAA/Publications, determined that Egypt, Lithuania and Spain are among the first places, in reference to the quality of the publications, see **Error! Reference source not found.**.

Table 1. Countries with the best ratio of citations to publications

#	*Country*	*Publications*	*TLCS*	*TGCS*	*TLCS/Publ.*	*TGCS/Publ.*
14	*Egipto*	*3*	*24*	*108*	*8,0*	*36,0*

23	*Lituania*	*1*	*5*	*18*	*5,0*	*18,0*
9	*España*	*5*	*20*	*60*	*4,0*	*12,0*
12	*Emiratos Árabes*	*4*	*14*	*72*	*3,5*	*18,0*
13	*Reino Unido*	*4*	*12*	*42*	*3,0*	*10,5*
2	*Turquía*	*24*	*64*	*252*	*2,7*	*10,5*
1	*Corea del Sur*	*43*	*92*	*346*	*2,1*	*8,0*

3.4 Publications by Institutions

The scientific capacity of an institution is reflected in the number of publications generated for a specific topic, in the specific topic of research related to the use of LPG in vehicles, as shown in Figure 2, it was determined that several South Korean university institutions have the highest number of publications, where Korea Institute Machinery & Materials stands out, with the highest number of records, Korea University in second place and Indian Institute of Technology in third place in India. For more detail, the top 5 institutions with the largest number of publications worldwide on LPG use in internal combustion engines are shown. In addition to the quantity of articles produced, the South Korean institutions have the highest number of citations, both in terms of FTAs and TGCS, with Korea University standing out, showing a high level of quality in scientific production.

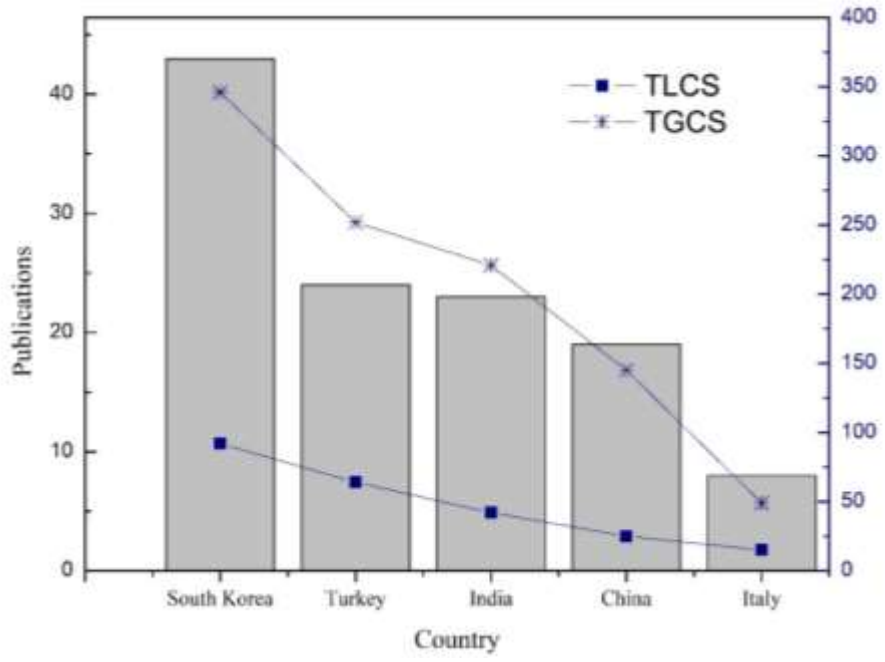

Figure 2. Number of publications by country.

3.5 Publications by journal

Of the 68 journals where the analyzed research on LPG use in combustion engines was published, only the first 5 are highlighted in Figure 3 for their greater number of publications, leading the list we have FUEL, with 11% of the total publications, in second place is APPLIED THERMAL ENGINEERING, 7% of the publications, in third place is INTERNATIONAL JOURNAL OF AUTOMOTIVE TECHNOLOGY, with 6%, and finally two magazines with the same number of publications ENERGY and ENERGY CONVERSION AND MANAGEMENT, both with 5% of the articles.

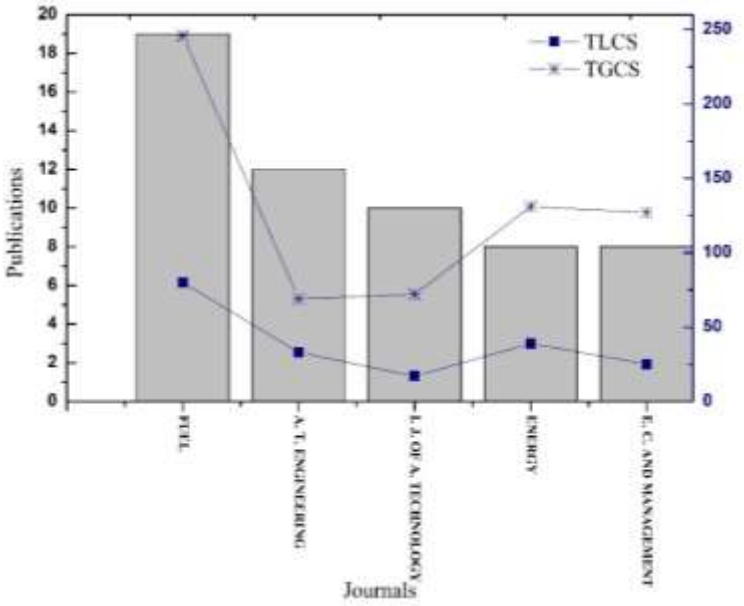

Figure 3. List of journals with more publications on LPG in combustion engines.

3.6 Publications and Authors of greater incidence

By determining the publications with the highest LCS (Local Citation Score) and GCS (Global Citation Score) indicators, the influence of the articles on the scientific community can be determined. In Table 2, the 10 most cited articles are shown, with their respective author, magazine and publication date data.

Table 2. Ten most frequently cited articles from the database.

#	Author / Title / Journal/ Date	LCS	GCS
1	40 Saleh HE; Effect of variation in LPG composition on emissions and performance in a dual fuel diesel engine; FUEL. 2008 OCT; 87 (13-14): 3031-3039	19	46
2	27 Ceviz MA, Yuksel F; Cyclic variations on LPG and gasoline-fuelled lean burn SI engine; RENEWABLE ENERGY. 2006 OCT; 31 (12): 1950-1960	13	39
3	30 Kwak H, Myung CL, Park S; Experimental investigation on the time resolved THC emission characteristics of liquid phase LPG injection (LPLi) engine during cold start; FUEL. 2007 JUL-AUG; 86 (10-11): 1475-1482	13	21
4	89 Masi M; Experimental analysis on a spark ignition petrol engine fuelled with LPG (liquefied petroleum gas); ENERGY. 2012 MAY; 41 (1): 252-260	12	19
5	49 Myung CL, Lee H, Choi K, Lee YJ, Park S; EFFECTS OF GASOLINE, DIESEL, LPG, AND LOW-CARBON FUELS AND VARIOUS CERTIFICATION MODES ON NANOPARTICLE EMISSION CHARACTERISTICS IN LIGHT-DUTY VEHICLES; INTERNATIONAL JOURNAL OF AUTOMOTIVE TECHNOLOGY. 2009 OCT; 10 (5): 537-544	11	29
6	75 Gumus M; Effects of volumetric efficiency on the performance and emissions characteristics of a dual fueled (gasoline and LPG) spark ignition engine; FUEL PROCESSING TECHNOLOGY. 2011 OCT; 92 (10): 1862-1867	11	19
7	24 Bayraktar H, Durgun O; Investigating the effects of LPG on spark ignition engine combustion and performance; ENERGY CONVERSION AND MANAGEMENT. 2005 AUG; 46 (13-14): 2317-2333	10	44
8	25 Murillo S, Miguez JL, Porteiro J, Gonzalez LML, Granada E, et al.; LPG: Pollutant emission and performance enhancement for spark-ignition four strokes outboard engines; APPLIED THERMAL ENGINEERING. 2005 SEP; 25 (13): 1882-1893	10	20
9	29 Yeom K, Jang J, Bae C; Homogeneous charge compression ignition of LPG and	9	42

	gasoline using variable valve timing in an engine; FUEL. 2007 MAR; 86 (4): 494-503		
10	19 Choi GH, Chung YJ, Han SB; Performance and emissions characteristics of a hydrogen enriched LPG internal combustion engine at 1400 rpm; INTERNATIONAL JOURNAL OF HYDROGEN ENERGY. 2005 JAN; 30 (1): 77-82	8	32

It is established that the 10 articles were written by 24 different authors, where Myung CL and Park S, both of Korean origin, can be highlighted, and that they simultaneously wrote 2 articles[15],[23] of the 10 most cited and that, in addition, from the global sample, they made 8 publications as shown in Figure 4, being among the authors who have published most on alternative thermal machines powered by liquefied petroleum gas worldwide. We also have Saleh HE who presents the article with the most citations, in accordance with the analysis in reference to the countries with the best list of citations by number of publications, in which Egypt topped the list due to the great contribution of this author.

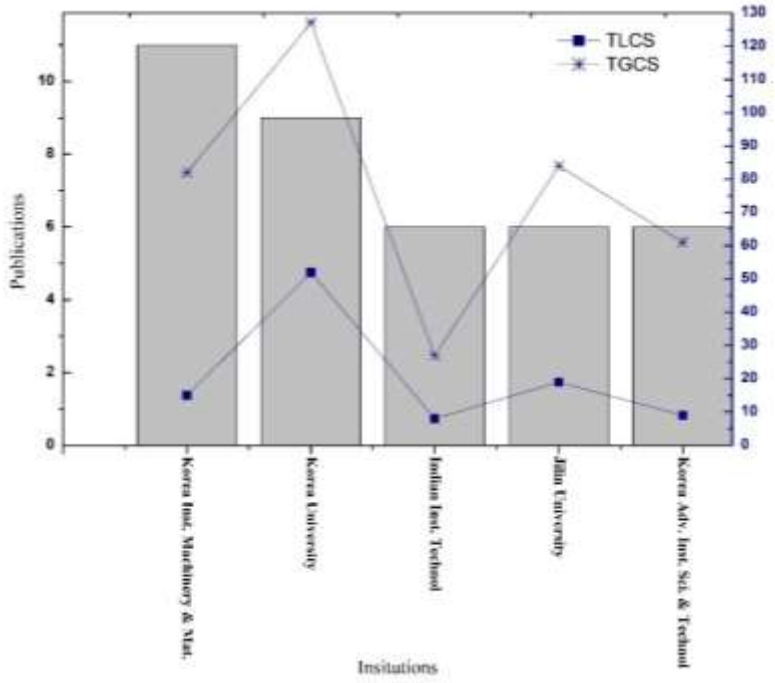

Figure 4. Institutions that have published most on LPG use in engines worldwide.

In the case of the magazines, we found that FUEL, ranks among the 10 most cited publications, 3 articles in the 1, 3 and 9, according to the magazine with the largest publications on LPG use in internal combustion engines. **Error! Reference source not found.** shows the authors with the greatest number of publications, as well as the TLCS and TGCS indices, where it is possible to highlight that these authors are of Korean origin.

Table 3. Authors with the greatest number of publications on the subject..

#	*Autor*	*Publications*	*TLCS*	*TGCS*
1	Kim J	9	30	69
2	Oh S	9	15	61
3	Choi K	8	39	104
4	Myung CL	8	52	125
5	Park S	8	52	125

A more complete analysis is determined by an analysis of the relationship between citations and the number of publications, thus showing the quality of scientific production. Figure 5, shows the authors with the highest number of this relationship, with Saleh HE again standing out in first place, in addition to Bayraktar H, Durgun O, Gonzalez LML and Ceviz MA, in the following positions. Table 3, shows the 10 publications with the highest number of citations among the niche articles determined for the use of LPG in internal combustion engines. The LCS (Local Citation Score) and GCS (Global Citation Score) indicators are detailed.

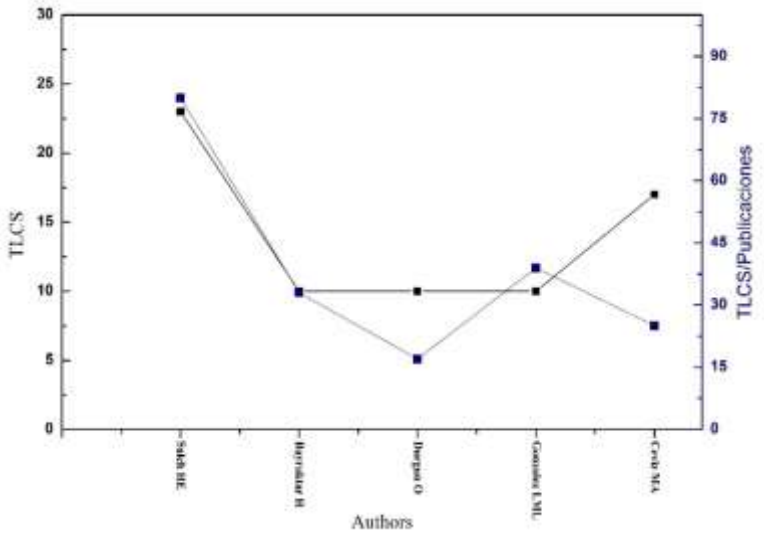

Figure 5. Authors with the greatest TLCS/Publications relationship on the subject.

3.7 Analysis of citations

In **Error! Reference source not found.**6, he describes the analysis of the chronology of citations of the most influential articles, shown for the LPG internal combustion engine topic, for which the 30 publications with the LCS citation indicator were selected from the 10 documents with the highest LCS. According to Table 7, the nodes show the number of the referenced publication, and the arrows point to the referenced articles. Among the most frequently quoted articles we find again the 40, corresponding to Saleh HE[13], where the effect of the variation in LPG composition on the emissions and performance characteristics of a dual fuel engine with diesel fuel and five LPG gaseous fuels with different compositions is investigated. However, for these 30 representative items we have in the first to 30, corresponding to Kwak H, Myung CL and Park S[15], which deals with the total hydrocarbon emission characteristics (THC) in liquid phase LPG injection engines (LPLi) during cold start operation.

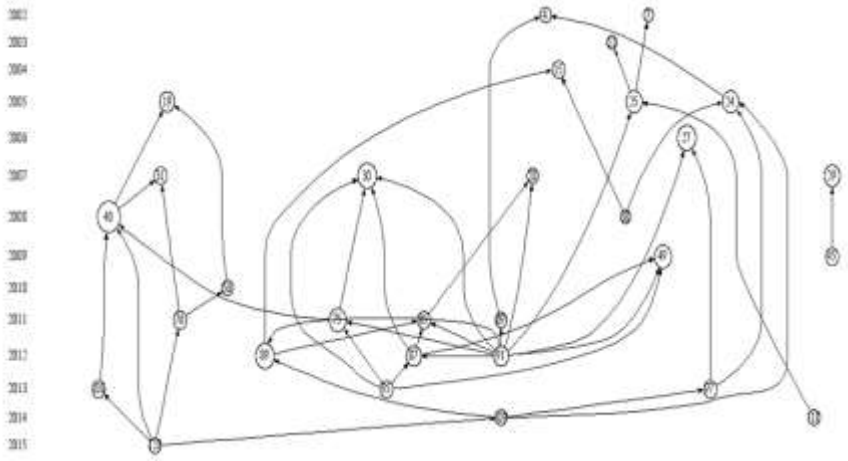

Figure 6. Citations over time for the 30 most cited publications.

IV.CONCLUSION

In conclusion, with the analysis carried out, it was possible to reach 5 important points, which are the trend in research into LPG-based internal combustion engines has been increasing since 2011, when they were introduced. The years with the greatest scientific production. Despite a fall in scientific publications in 2014, the number of publications has increased in the two previous years (2015 and 2016), so much so that 2016 has been the year with the highest scientific production on the subject.

The eagerness for new forms of energy to balance the use of fossil fuels in the traditional automotive transport industry, together with the need for less polluting energies, has accelerated the diversification of other types of energy in the traditional diesel and petrol transport sector. This has led to ongoing research to replace or supplement traditional fuels.

LPG as a fuel for vehicle use, has had a great development in countries such as South Korea, Turkey, India, China and Italy, as can be verified being the largest producers of scientific publications on this subject. Additionally, in these countries LPG has been an adequate fuel in support of conventional diesel and gasoline.

Currently the best positioned research centers in the world on LPG research for internal combustion engine use are South Korea, given the number of annual publications and the analysis of the citations that these articles have.

REFERENCES

[1] F. Alrawi, "The importance of intelligent transport systems in the preservation of the environment and reduction of harmful gases," *Transportation Research Procedia*, vol. 24, pp. 197–203, 2017.
[2] O. Dinu *et al.*, "ScienceDirect ScienceDirect ScienceDirect ScienceDirect the Society timing of replacing transport means Costing models for capacity optimization About the timing of replacing transport means," *Procedia Manufacturing*, vol. 22, pp. 848–855, 2018.
[3] D. Pyza, R. Jachimowski, I. Jacyna-Gołda, and K. Lewczuk, "Performance of Equipment and Means of Internal Transport and Efficiency of Implementation of Warehouse Processes," *Procedia Engineering*, vol. 187, pp. 706–711, 2017.
[4] C. Lowe, J. Stanley, and J. Stanley, "A broader perspective on social outcomes in transport," *Research in Transportation Economics*, no. March, pp. 0–1, 2018.
[5] A. Ugurlu and S. Oztuna, "A comparative analysis study of alternative energy sources for automobiles," *International Journal of Hydrogen Energy*, vol. 40, no. 34, pp. 11178–11188, 2015.
[6] J. Shi *et al.*, "Life cycle environmental impact evaluation of newly manufactured diesel engine and remanufactured lng engine," *Procedia CIRP*, vol. 29, pp. 402–407, 2015.
[7] H. Caliskan, "Environmental and enviroeconomic researches on diesel engines with diesel and biodiesel fuels," *Journal of Cleaner Production*, vol. 154, pp. 125–129, 2017.
[8] Y. Bicer and I. Dincer, "Life cycle environmental impact assessments and comparisons of alternative fuels for clean vehicles," *Resources, Conservation and Recycling*, vol. 132, no. January, pp. 141–157, 2018.
[9] A. F. Jensen and S. L. Mabit, "The use of electric vehicles: A case study on adding an electric car to a household," *Transportation Research Part A: Policy and Practice*, vol. 106, no. April 2016, pp. 89–99, 2017.
[10] G. Brandstätter, M. Kahr, and M. Leitner, "Determining optimal locations for charging stations of electric car-sharing systems under stochastic demand," *Transportation Research Part B: Methodological*, vol. 104, pp. 17–35, 2017.
[11] T. Wilberforce *et al.*, "Developments of electric cars and fuel cell hydrogen electric cars," *International Journal of Hydrogen Energy*, vol. 42, no. 40, pp. 25695–25734, 2017.
[12] J. Baggemann, W. Jahn, S. Kelm, E. A. Reinecke, and H. J. Allelein, "Numerical study on the influence of different boundary conditions on the efficiency of hydrogen recombiners inside a car garage," *International Journal of Hydrogen Energy*, vol. 42, no. 11, pp. 7608–7616, 2017.
[13] T. Ho and V. Karri, "Hydrogen powered car: Two-stage modelling system," *International Journal of Hydrogen Energy*, vol. 36, no. 16, pp. 10065–10079, 2011.
[14] G. Wang, "The role of hydrogen cars in the economy of California," *International Journal of Hydrogen Energy*, vol. 36, no. 2, pp. 1766–1774, 2011.
[15] C. Bae and J. Kim, "Alternative fuels for internal combustion engines," *Proceedings of the Combustion Institute*, vol. 36, no. 3, pp. 3389–3413, 2017.
[16] C. C. Chang, J. G. Lo, and J. L. Wang, "Assessment of reducing ozone forming potential for vehicles using liquefied petroleum gas as an alternative fuel," *Atmospheric Environment*, vol. 35, no. 35, pp. 6201–6211, 2001.
[17] P. Geng, E. Cao, Q. Tan, and L. Wei, "Effects of alternative fuels on the combustion characteristics and emission products from diesel engines: A review," *Renewable and Sustainable Energy Reviews*, vol. 71, no. December 2016, pp. 523–534, 2017.
[18] J. L. Osorio-Tejada, E. Llera-Sastresa, and S. Scarpellini, "A multi-criteria sustainability assessment for biodiesel and liquefied natural gas as alternative fuels in transport systems," *Journal of Natural Gas Science and Engineering*, vol. 42, pp. 169–186, 2017.
[19] L. Raslavičius, A. Keršys, S. Mockus, N. Keršiene, and M. Starevičius, "Liquefied petroleum gas (LPG) as a medium-term option in the transition to sustainable fuels and transport," *Renewable and Sustainable Energy Reviews*, vol. 32, pp. 513–525, 2014.
[20] V. S. Yaliwal, N. R. Banapurmath, N. M. Gireesh, and P. G. Tewari, "Production and utilization of renewable and sustainable gaseous fuel for power generation applications: A review of literature," *Renewable and Sustainable Energy Reviews*, vol. 34, pp. 608–627, 2014.
[21] P. By, "Liquefied Petroleum Gas (LPG) as a Fuel for Internal Combustion Engines."
[22] M. I. Karamangil, "Development of the auto gas and LPG-powered vehicle sector in Turkey: A statistical case study of the sector for Bursa,"

Energy Policy, vol. 35, no. 1, pp. 640–649, 2007.
[23] R. Biscoff, M. Akple, R. Turkson, and W. Klomegah, "Scenario of the emerging shift from gasoline to LPG fuelled cars in Ghana: A case study in Ho Municipality, Volta Region," *Energy Policy*, vol. 44, pp. 354–361, 2012.
[24] Propane Education and Research Council, "Converting Vehicles to Propane Autogas Part 1 : Installing Fuel Tanks and Fuel Lines," 2011.
[25] M. de M. y E. Unidad de Planeación Minero Energética, "Cadena del Gas Licuado del Petroleo 2013," vol. 53, no. 9. p. 63, 2013.
[26] D. H. Qi, Y. Z. Bian, Z. Y. Ma, C. H. Zhang, and S. Q. Liu, "Combustion and exhaust emission characteristics of a compression ignition engine using liquefied petroleum gas-Diesel blended fuel," *Energy Conversion and Management*, vol. 48, no. 2, pp. 500–509, 2007.
[27] C. L. Myung, K. Choi, J. Kim, Y. Lim, J. Lee, and S. Park, "Comparative study of regulated and unregulated toxic emissions characteristics from a spark ignition direct injection light-duty vehicle fueled with gasoline and liquid phase LPG (liquefied petroleum gas)," *Energy*, vol. 44, no. 1, pp. 189–196, 2012.
[28] H. E. Saleh, "Effect of variation in LPG composition on emissions and performance in a dual fuel diesel engine," *Fuel*, vol. 87, no. 13–14, pp. 3031–3039, 2008.
[29] M. Masi, "Experimental analysis on a spark ignition petrol engine fuelled with LPG (liquefied petroleum gas)," *Energy*, vol. 41, no. 1, pp. 252–260, 2012.
[30] U. de P. M. E. UPME, "Cadena del Gas Licuado del Petroleo 2017," p. 88, 2017.
[31] M. G. Chaparro and G. Cobuzio, "Evaluación del uso de Gas licuado de petróleo en vehículos automotores convencionales sobre territorio colombiano." p. 158, 2015.
[32] U. de P. M. E.-U. Universidad Nacional de Colombia; UPME, "COMBUSTIBLE EN EL SECTOR TRANSPORTE Tomo I," vol. 1. pp. 1–118, 2014.
[33] Colfecar, "Gas licuado de petróleo: ¿una opción de combustible para el transportador de carga por carretera?," pp. 1–15.
[34] Ministerio de Minas y Energía de Colombia, "37098-Resolución-40577-09 Junio 2016." p. 4, 2016.
[35] R. Zeng and A. Chini, "A review of research on embodied energy of buildings using bibliometric analysis," *Energy and Buildings*, vol. 155, pp. 172–184, Nov. 2017.
[36] I. S. Yulineth Cardenas, Guillermo Valencia, "Análisis cienciométrico de la investigación de sistemas fotovoltaicos integrados a edificios desde el año 2000 a 2017," *Revista Espacios*, vol. 38 (Nº 47), pp. 1–12, 2017.
[37] H. Q. Chen *et al.*, "Chinese energy and fuels research priorities and trend: A bibliometric analysis," *Renewable and Sustainable Energy Reviews*, vol. 58, pp. 966–975, May 2016.