Research Hotspots and Trends of Natural Gas Vehicles: A Visual Analysis Using CiteSpace

Na Luo1, *, Meihui Li2, a, Jingqi Dai1, b
1Chongqing Business Vocational College, Chongqing, China
2Business School, Chengdu University, Chengdu, China
3Institute of New Energy and Low-Carbon Technology, Sichuan University, Chengdu, China

*Corresponding author e-mail: 624761781@qq.com, limehui0430@163.com,
daijingqi@stu.scu.edu.cn

Abstract. Driven by the optimization of energy structure, environmental pollution control and climate change constraints, natural gas vehicles have high development potential. As a vehicle fuel, natural gas has many advantages, such as abundant reserves, excellent fuel economy and relatively less pollutants, which makes the development of natural gas vehicles more rapid. This paper uses the data analysis system (DAS) composed of Web of Science (WOS) and CiteSpace to sort out the related literature of natural gas vehicles. Through the visual analysis of 529 documents, the research hotspots and trends of natural gas vehicles from 1990 to now are found. Three important clusters are discussed in this paper, among which the future development direction of natural gas vehicles is hybrid gas-electric vehicles, in order to provide reference for the R&D and production activities of natural gas vehicles.

1. Introduction
Facing the lack of resources and environmental pollution, there is a key research being carried out, that is, using natural gas as vehicle fuel [1]. Natural gas is the cleanest fossil fuel to burn, and its methane content is generally more than 90%. It is a good automobile engine fuel. Compared with gasoline and diesel vehicles, natural gas vehicles (NGVs) have better comprehensive advantages in technical reliability, economy, environmental protection and safety, especially in heavy trucks [2]. There are four main power sources of NGVs: CNG single fuel engine (the fuel is natural gas or natural gas mixed with hydrogen), CNG/gasoline dual-fuel engine, CNG/diesel dual-fuel engine and liquefied natural gas (LNG) engine [3, 4].

The earliest use of natural gas as fuel began in the first World War, at that time, atmospheric capsules were used to load natural gas as automobile fuel to solve the problem of automobile fuel shortage in wartime [5]. Using compressed natural gas (CNG) as automobile fuel began in Italy in 1930s [6]. But it was not been applied widely for the large resistance of natural gas package, less gas storage, and easy to leak gas, the vehicle mileage is short. It was not until 1970s that with the progress of material science and manufacturing process, CNG vehicles and supporting facilities are maturing, which makes the use of natural gas on vehicles possible. On the other hand, after the first oil crisis in 1973, people gradually...
recognized the advantages of using natural gas for automobiles, such as economy, cleanliness and safety, and promoted its technological progress and development [7].

2. Development status of NGVs

Fig.1 shows the general distribution of NGVs and fueling stations around the world. According to the statistics of ‘NGV Global’ [8], as of July 2019, there are 23,001,733 NGVs and 28,376 gas fueling stations in the world. Among them, the number of NGVs and gas fueling stations in the Asia Pacific region ranks first in the world, with China having the largest number of 6,760,000, accounting for 24.6% of the total, and about 9,000 gas fueling stations, followed by Iran, India, Pakistan, etc. It can be seen that the global total amount of vehicles is mainly concentrated in developed countries, but the total amount of NGVs is mainly concentrated in developing countries. This shows that developing countries pay more attention to and demand for NGVs than developed countries. The technology level of developing countries in the field of NGVs is generally lagging behind that of developed countries, but its popularization and application are ahead.

![Figure 1. Global distribution of NGVs and fueling stations.](image)

Fig. 2 shows the changes in the number of NGVs and gas fueling stations in five states from 1996 to 2019. It can be found that the Asia Pacific region gradually began to surpass Latin America after 2004. The research shows that the main reason for the rapid development of NGVs in the Asia Pacific region is that the government has formulated and implemented a series of incentives [9]. There are also reasons to save crude oil for export. Iran, for example, has seen rapid development of NGVs since 2004 [10].

![Figure 2. Trends of regional NGVs and natural gas fueling stations.](image)
3. Methodology
In this paper, ISI Web of Science is used as the data source, and CiteSpace visual analysis tool is used to analyze the keywords distribution, clustering status and literature evolution law in the related research literature of NGVs. The research status, hotspots and trends of NGVs are found and sorted out. Fig. 3 is a data analysis system (DAS) established in this paper.

![Data Analysis System](image)

**Figure 3.** DAS and literature mining.

3.1. Web of Science
ISI Web of Science is the largest comprehensive academic information resource covering the most disciplines in the world [11]. Using the rich and powerful retrieval function of WOS, we can fully understand the research information about a subject. In this paper, six citation libraries of WOS, such as SCI-Expanded, SSCI, A&HCI, are used for advanced retrieval of documents with the title of ‘natural gas vehicle’ and other subject words. The document type is ‘Article, Review, Procedures paper’, the time range is 1990-2020 (Retrieved on February 7, 2020), and 529 effective documents are obtained.

3.2. CiteSpace
In scientific research, we often need to face a large number of documents. How to find out the key documents worthy of intensive reading and close reading in these documents, excavate the frontier of the discipline and find the research hotspot has become the first problem to be solved before carrying out the research. CiteSpace is a software used to identify and display the new trends and trends of scientific development in the scientific literature [12]. It can mine the information we need in the massive literature data with relatively simple operation steps. It can not only help us sort out the past research track, but also make us have a general understanding of the future research prospects.

CiteSpace provides three visual options [13], the default one is Cluster, which focuses on reflecting the structural characteristics of clusters, highlighting key nodes and important connections; the Timeline
view focuses on the relationship between clusters and the historical span of documents in a cluster, and the Timezone view is another view which focuses on representing knowledge evolution from time dimension. It can clearly show the update and interaction of literature. These maps can be used to reveal the development and even change of scientific structure, and then used for frontier analysis, field analysis, scientific research evaluation, etc., but for specific research problems, we should choose according to different mapping principles.

4. Visualization results
CiteSpace provides a variety of functional options, including cooperative (Author, Institution, Country) and co-occurrence maps (Term, Keyword, Category) for cited documents and co-citation maps (Cited reference, Cited author, Cited Journal) for cited documents.

4.1. Collaboration atlas
The Country cooperation network map generated by CiteSpace can identify the distribution of NGVs research in different countries, as shown in Fig. 4. In Fig. 4, the node represents different countries, the size of the node represents the number of documents; the line represents the cooperation between countries, and the thickness of the line represents the strength of cooperation.

![Figure 4. Country cooperation and affiliations.](image-url)

First of all, most studies are in the United States, China, France, Canada, Britain, Italy, Germany, Brazil, Norway, Iran, etc. Italy is the first country to use compressed natural gas (CNG) as automobile fuel; the United States, Canada, Germany and other countries have the world's advanced R&D and manufacturing technologies for natural gas vehicle engines, fueling stations and other equipment. For China, by the end of 2018, there are 6.7 million NGVs and 9000 natural gas fueling stations [8]. So there are many literatures about NGVs in these countries. Later researchers can learn from their achievements, not only to study their advanced technology, but also to learn their policies on promoting the development of natural gas vehicles, and even to solve the problems they put forward in the research.
According to the Centrality ranking, it is found that 16 countries have cooperative relationships with other countries. As shown in Figure 5, many authors seem to like to cooperate across countries. This discovery may link related knowledge and enable different countries to obtain shared research results. But there are still many authors who like to work with researchers in their own countries, such as Netherlands, Poland, Greece, Ireland, etc. At the same time, we find that Norway and China have burst. CiteSpace provides burst-detection to detect the situation that the reference volume changes greatly in a certain period of time, so as to find the decline or rise of a subject word or keyword [14]. Through literature search, it is found that research between Norway and other countries increased abruptly from 2004 to 2009, and research between China and other countries increased abruptly from 2018 to 2020.

| Centrality | Author       | Burst | Freq |
|------------|--------------|-------|------|
| 0.52       | ENGLAND      | 14    | 0    |
| 0.3        | SWEDEN       | 5     | 0    |
| 0.29       | FRANCE       | 28    | 0    |
| 0.29       | BRAZIL       | 15    | 0    |
| 0.22       | USA          | 111   | 0    |
| 0.18       | NORWAY       | 3.7   | 21   |
| 0.15       | SAUDI ARABIA | 4     | 0    |
| 0.11       | IRAN         | 3     | 0    |

| Centrality | Author       | Burst | Freq |
|------------|--------------|-------|------|
| 0.11       | SCOTLAND     | 16    | 0    |
| 0.08       | CANADA       | 7     | 0    |
| 0.08       | PAKISTAN     | 3     | 0    |
| 0.08       | DENMARK      | 29    | 0    |
| 0.04       | CHINA        | 3.65  | 11   |
| 0.04       | ITALY        | 52    | 0    |
| 0.04       | SPAIN        | 6     | 0    |
| 0.04       | JAPAN        | 16    | 0    |

Figure 5. Countries are ranked according to centrality.

4.2. Co-occurrence atlas

The keywords of a paper reflect the core theme and main content of the paper [15], so the analysis of keywords can understand the research hotspot of natural gas vehicles. Cluster analysis refers to the analysis process of grouping abstract objects into multiple classes composed of similar objects based on the similarity of analysis objects. This paper uses 'cluster view' to analyze the research hotspots and development trends of NGVs. Here, by discovering clusters, extracting tags, evaluating parameters, and identifying specific points and clusters, the trend of keywords (and their clusters) can be found. In order to simplify the network and highlight the important structural features, the minimum spanning tree is used to prune the network. According to the spectrum clustering algorithm for automatic clustering, Log likelihood rate (LLR) weighted algorithm is used to extract clustering labels, and the keywords co-occurrence network knowledge map is obtained as shown in Fig. 6.

Through automatic labeling, 66 clusters are found, and then we select some important clusters to display in the graph according to the contour and size. The color of clustering represents time: the warmer the color, the closer the time; the colder the color, the longer the time goes by. From the Fig. 6, we can see that the research hot spots of natural gas vehicles include the types of natural gas vehicles, the discussion of relevant policies, the impact of vehicles on the environment, the choice of fuel, vehicle technology, etc. There are still some clusters not shown, such as the economic aspects of CNG vehicles, the design, control and performance of CNG engines, the combustion and fuel injection characteristics of CNG engines, and the safety aspects of natural gas vehicles.
5. Discussion

From Fig. 6, it can be found that the color of clusters 1, 5 and 7 are warm, which shows that this topic is the current research hotspots, so this part mainly discusses the reasons for the emergence of these three clusters.

- the ID=1 cluster label was ‘climatic change’, which introduces the cleanliness of NGVs.
- the ID=5 cluster label was ‘policy', mainly analyzing how the policy affects the development of NGVs.
- the ID=7 cluster label was 'technologies', mainly introducing a new research direction of NGVs.

5.1. Environment

The exhaust emission of transportation industry has become one of the most prominent environmental and socio-economic problems. The oil industry is moving towards alternative fuels for a variety of reasons, including climate change caused by increased greenhouse gas emissions, as well as political and social instability related to oil supply and prices. CNG is considered as one of the main alternative fuels of green transportation fuel. The main component of natural gas is methane, which is the simplest alkane with only one carbon atom, so there is no C-C bond. The simple chemical structure of methane makes it an inherent clean combustion fuel [16]. When used as engine fuel, this results in low particulate (PM) emissions and low toxicity of exhaust particulates. Table 1 [17] is the fuel coefficient emission table of natural gas, gasoline and diesel. It can be seen that the development of natural gas vehicles with gas instead of oil is a green environmental protection project, which can effectively reduce carbon dioxide emissions, and is of great significance to create a harmonious environment between human and nature.
Table 1. Fuel emission coefficient and attribute comparison.

|                           | Natural gas | Gasoline | Diesel oil |
|---------------------------|-------------|----------|------------|
| CO2 Potential Emission Coefficient (kg/GJ) | 56.224      | 69.363   | 74.024     |
| Autoignition Point /°C    | 650         | 427      | 260        |
| Explosion limit           | 5-15        | 1-7      | 0.5-4.1    |
| Density (kg/m³)           |             |          |            |
| Liquid                    | 423         | 725      | 835        |
| Gaseous                   | 0.7167      | 5.093    | —          |

To view articles related to environment, research topics include: experimental comparative analysis of CNG in dual-fuel engines, CNG's impact on air quality; comparative life cycle emission analysis of CNG; physical characteristics of regulated and unregulated emissions of CNG vehicles; CNG reduction through carbon emission assessment; road measurement of regulated pollutants in diesel and CNG vehicles; CNG And the real-time measurement of nitrogen oxide in diesel transportation; the influence of CNG composition on the specified emission expansion of CNG fuel wheels; the environmental benefits of CNG buses; the comparison of ultra-fine particle emissions of diesel and CNG vehicles.

5.2. Policy incentives
The natural gas automobile industry is the industry that gives the most preferential policies in many countries.

1) China's policies and measures mainly include: actively promoting the construction of natural gas infrastructure; reducing the taxes and fees of gas vehicles, urban capacity increase fees, passenger transport management fees, etc., and providing financial subsidies for the purchase or modification of natural gas vehicles; formulating price policies to ensure the reasonable price difference between oil and gas; enterprises that produce gas devices on a regular basis enjoy preferential treatment from local enterprises; Appropriate administrative subsidies shall be given to taxi companies, public transport companies and administrative institutions that use gas vehicles.

2) In the United States, the natural gas vehicle policy mainly includes the following four aspects: the property tax credit for automobiles; the increase of the fuel property tax credit for CNG or LNG filling stations; the requirement that at least 50% of the federal government's newly purchased and in use vehicles use CNG or LNG as fuel; the provision of subsidies for the development of light and heavy natural gas engines and vehicles .

3) Japan adopts natural gas vehicle purchase and infrastructure construction support, as well as the government's partial use of natural gas vehicles policy.

4) In order to support and encourage the development of natural gas vehicles, Italy implements vehicle purchase tax preference, vehicle purchase/replacement subsidy, infrastructure construction subsidy and vehicle natural gas price control.

5) Other countries with rapid development of natural gas vehicles have generally adopted policies such as tax relief and financial subsidies for the construction of natural gas vehicles and their gas stations.

5.3. Hybrid gas-electric vehicles
There are many kinds of natural gas vehicles. Through clustering, we find a relatively new technology, namely hybrid gas-electric vehicles (HGEV). By reviewing the relevant literature, it is found that this is a future development trend of NGVs.

In order to save resources and use new energy effectively, hybrid electric vehicle (HEV) is produced according to the demand [20]. The driving force is provided by gasoline-electric hybrids, which reduces the fuel consumption and environmental pollution, and therefore can be developed and put into use rapidly. At the same time, the emergence and use of electric vehicles also bring hope for energy-saving vehicles. One of the characteristics of HGEV is that the driving force of the vehicle is driven by gas and electricity, which can achieve low emissions and low pollution. Therefore, with its great advantages in
environmental protection, it quickly enters the market and obtains certain competitiveness. However, compared with the oil electric hybrid vehicle, the gas electric hybrid vehicle has lower power performance and greater power consumption, so the battery pack capacity is large. After driving a large mileage, the battery needs to be charged from the external grid. Therefore, it is not enough to become the mainstream development of new energy.

In the long run, there is no doubt that the HGEV has a good development prospect. But if we want to make its energy management better, so that it can recover the energy, start and stop the engine at any speed, frequently and smoothly, achieve the optimization of energy saving and emission reduction in the economic mode, we need better design and adjustment. It is understood that in a long period of time in the future, energy-saving vehicles will also develop and improve rapidly. It is understood that in a long period in the future, energy-saving vehicles will also develop and improve rapidly. In the near future, it is likely to start with the research of hybrid electric power to reduce fuel consumption and emissions; in the long term, the effective use of clean energy resources will be the power source, which will greatly improve the energy-saving, efficient and environmental friendly automobile industry.

6. Conclusion
Natural gas is a new energy which can replace the traditional automobile fuel. The promotion and use of natural gas fuel vehicles is not only the need of energy structure adjustment, but also in line with the requirements of building an energy-saving economy, and also an effective means of environmental governance. In order to clarify the development status and research focus of natural gas vehicles, as well as the possible development direction in the future, CiteSpace visual analysis software is used for empirical research. It is found that the future development direction of natural gas vehicles is toward gas electric hybrid. This is an important finding of the study that can be provided to relevant researchers. There are opportunities and challenges for the development of NGVs. We should seize the opportunity and vigorously promote the application of NGVs, which is of great significance to improve the atmospheric environment quality, reasonably develop and utilize natural gas resources, reduce the cost of automobile fuel and realize the strategy of sustainable development.

References
[1] Tong, Fan, Jaramillo, Paulina, Azevedo, Inês M. L. Comparison of Life Cycle Greenhouse Gases from Natural Gas Pathways for Light-Duty Vehicles[J]. Energy & Fuels, 29(9):6008-6018.
[2] Hesterberg T W , Lapin C A , Bunn W B . A Comparison of Emissions from Vehicles Fueled with Diesel or Compressed Natural Gas[J]. Environmental Science & Technology, 2008, 42(17):6437-6445.
[3] J. Mao, Z. Hao, Q. Zhang. An analysis on the noise roughness of a gasoline/CNG dual fuel engine[J]. Qiche Gongcheng/automotive Engineering, 2015, 37(3):331-335.
[4] Königsson F. On Combustion in the CNG-Diesel Dual Fuel Engine[J]. 2014.
[5] Wolfgang Sassin. Fossil Energy and its Alternatives: A Problem Beyond Costs and Prices[M]. Palgrave Macmillan UK, 1987.
[6] M. Pacione. Natural gas in Italy[J]. Geography, 1979, 64(3):211-215.
[7] Hafezi, Reza, Akhavan, AmirNaser, Pakseresht, Saeed. Projecting plausible futures for Iranian oil and gas industries: Analyzing of historical strategies[J]. Journal of Natural Gas Science & Engineering, 39:15-27.
[8] http://www.iangv.org/current-ngv-stats/
[9] Talus, Kim. United States natural gas markets, contracts and risks: What lessons for the European Union and Asia-Pacific natural gas markets? [J]. Energy Policy, 74:28-34.
[10] Office U S G A. Firms Reported in Open Sources as Having Commercial Activity in Iran's Oil, Gas, and Petrochemical Sectors[J]. 2011.
[11] Susanne Mikki. Comparing Google Scholar and ISI Web of Science for Earth Sciences[J]. 82(2):321-331.
[12] Chaomei Chen. CiteSpace II: Detecting and visualizing emerging trends and transient patterns in
scientific literature[J]. Journal of the Association for Information Science & Technology, 2006, 57(3):359-377.

[13] Muaz Niazi, Amir Hussain. Agent-based computing from multi-agent systems to agent-based models: a visual survey[J]. Scientometrics, 89(2):479-499.

[14] Shingo Tamura, Keiichi Tamura, Hajime Kitakami. Clustering-based burst-detection algorithm for web-image document stream on social media[C]// Systems, Man, and Cybernetics (SMC), 2012 IEEE International Conference on. IEEE, 2012.

[15] Raikow R J. Keywords in Evolutionary Biology[M]// Keywords in evolutionary biology /. 1994.

[16] Alvarez R A, Pacala S W, Winebrake J J, et al. Greater focus needed on methane leakage from natural gas infrastructure.[J]. 2012, 109(17):6435-6440.

[17] https://wenku.baidu.com/view/fb17d2e527d3240c8447efe6.html

[18] Ma, Linwei, Geng, Jia, Li, Weqi. The development of natural gas as an automotive fuel in China[J]. Energy Policy, 62(Complete):531-539.

[19] Spearrin, R. Mitchell, Triolo, Ryan. Natural gas-based transportation in the USA: economic evaluation and policy implications based on MARKAL modeling[J]. International Journal of Energy Research, 38(14):1879-1888.

[20] InChun Chung, Hyehyun Kang, Jinil Park. Fuel Economy Improvement Analysis of Hybrid Electric Vehicle[J]. International Journal of Automotive Technology, 2019, 20(3):531-537.