The Scientometric Evaluation on the Research of Biofuels Based on CiteSpace

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***Abstract*—As one of the alternative fuels for petroleum, biofuels are an important part of biomass and play an important role in ensuring energy security, coping with climate change and building ecological civilization. This paper selects the Web of Science Core Collection database as the data source, uses the scientometric analysis method, and CitaSpace measurement tool to analyze the number of countries, institutions, subject, key papers and research hotspots from 1990 to 2017. The research findings are as follows:(1) The biofuels papers are generally on an upward trend;(2) USA, China, India, Brazil, Germany are the five biggest contributing countries on biofuels;(3) The main subject of biofuels are Energy Fuels, Biotechnology Applied Microbiology, Engineering Chemical, Environmental Sciences, Agricultural Engineering; (4) The research on biofuels has been well diffused globally with many research centers and institutions of university; (5) Research hotspots such as lignocellulosic biomass, biodiesel, fuel ethanol, and microalgae oil also gradually change with time. At present, bioethanol production and lignocellulosic biomass energy are important research directions.**

Keywords*—biofuel; scientometric analysis; CiteSpace; biodiesel; bioethanol

I. INTRODUCTION

A. The Importance of the Biofuel Research

Biofuel, as one of the alternative fuels for petroleum, is an important direction for the development of renewable energy and one of the major technologies for global climate change. Biofuels include bioethanol, biodiesel, lignocellulosic biomass, bio-hydrogen, bio-oil, biogas, and the like. The world's major countries include USA, Canada, and Brazil have set minimum standards for the addition of renewable fuels to transportation fuels [1-2]. According to ***BP2030 World Energy Outlook***, the share of natural gas and non-fossil fuels in the energy structure will increase, while the share of coal and oil will decrease accordingly. Renewable energy, including biofuels, is expected to grow at an average annual rate of 8.2% between 2010 and 2030, making it the fastest growing fuel in the world [3].

Sustainable and cost-efficient production of biofuels is necessary. Gonzalez et al. review anaerobic digestion is an area with strong potential for novel research focusing on the development of a sustainable integrated system of biodiesel and biogas production [4-5].

Biofuels such as biodiesel, biomethane and bioethanol have great potential and social value, which have been provided by many researchers [6-10].

B. The Importance of Scientometric Research about Biofuels

There has been a significant interest in the research community in the general to evaluate the research activities 编 by using of scientometric methods [11].

Many findings are as follows through scientometric research about energy. Ma et al. extracts research hotspots from the 30 most frequently used author keywords [12]. Based on the Science Citation Index Expanded (SCIE) of the Web of Science, a bibliometric analysis was conducted to characterize the body of knowledge on microalga-derived biodiesel between 1993 and 2016.

Leu et al. find that the key technologies for biofuel energy have reached technological maturity in the US [13]. In addition, three important subjects are found from citation techniques, which are related to biodiesel fuel, biological fuel cell, and the biohydrogen. The status and activity of technological development in the field of biofuels and biohydrogen energy from the year 2000-2011 are investigated by utilizing patent bibliometric analysis.

Chen et al. summarize an overview of Chinese energy and fuels research [14]. Bibliometric analysis has been used to data extracted from the Science Citation Index Expanded (SCIE) database from 1993 to 2012. The results show that biomass and biodiesel were the most important topic.

Mao et al. find that the production of biogas, biodiesel and bioethanol was most popular in the bioenergy related studies [15]. A bibliometric analysis of the research output is carried out using the Science Citation Index-Expanded (SCIE) and the Social Sciences Citation Index (SSCI) to depict existing research activities on alternative energy and future directions.

Further references including the literature reviews are provided as in the list of most cited papers and hottest papers on the biofuels in this paper.

C. Issues

A good foundation has been laid for the research of biofuels, but there are also shortcomings such as short time series, too large or too small research topics, and single research methods. In addition, there has been no published by the Web of Science Core Collection full study of the research on the biofuels covering the period from 1990 to 2017 at a global scale in the scientific community as of October 2018.

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Therefore, the aim of this paper is to carry out the scientometric evaluation on the global research on the biofuels to identify the main trends and issues in this field, based on data extracted from the Web of Science Core Collection database from 1990 to 2017. In order to provide reference and helpful insights for relevant researchers and decision makers in the field of biofuels.

II. MATERIAL AND METHODS

A research is carried out by using the Web of Science Core Collection database of the Clarivate Analytics in the October 2018.

The search terms used were [TS=biofuel OR TS="bio-fuel" OR TS="Biological fuel" OR TS=Biodiesel OR TS="bio-diesel" OR TS="biological diesel" OR TS=Biomethane OR TS="Bio-methane" OR TS="Biological methane" OR TS= Bioethanol OR TS="bio-ethanol" OR TS="Biological ethanol" OR TS=(Ethanol NEAR/0 fuel) OR TS=(Renewable NEAR/5 Diesel) OR TS=Biobutanol OR TS="Bio-butanol" OR TS="biological butanol" OR TS=(Cellulose NEAR/5 alcohol) OR TS=bioalcohol* OR TS=biological alcohol OR TS=Biogas OR TS="bio-gas" OR TS="biological gas" OR TS=Biosyngas OR TS="Bio-syngas" OR TS="Biological syngas" OR TS="bio-oil" OR TS="biological oil" OR TS="bio-gasoline" OR TS=biogasoline OR TS="biological gasoline" OR TS= (Algae NEAR/5 Biofuel) OR TS=biohydrogen OR TS="bio-hydrogen" OR TS="Biological hydrogen" OR TS=(hydrotreat* NEAR/5 "Vegetable oil")] in the topic (include abstract , title, keywords)].

The search terms were based on the definition of biofuels by the World Intellectual Property Organization (WIPO), reading biofuel-related literature, and consulting experts in the field of energy.

Then, the search was refined restricting the research to “article”, “review” and “proceedings papers” to locate the core papers mostly related to biofuels. Exclude irrelevant subjects, finally, 98,860 papers were extracted from the search result from 1990 to 2017.

CiteSpace is an information visualization software developed by the Java language. It is based on co-citation theory and pathfinder algorithm to measure specific domain documents (sets). It is a citation visualization analysis software that focuses on analyzing the potential knowledge contained in the literature and is gradually developed in the context of scientometrics and data visualization. It has functions include co-citation analysis, co-occurrence analysis, and cooperative network analysis. Databases that can be used for analysis include China National Knowledge Infrastructure (CNKI), Chinese Social Sciences Citation Index (CSSCI), Web Of Science (WOS), Scopus [17-18].

Next, a scientometric analysis is carried out using CiteSpace and WOS database. The used tool are “publication year”, “countries/regions”, “institution” and “categories”.

And then, a systematic analysis of the papers from 1990 to 2017 is carried out in terms of quantity, country/region, institutional, key subjects, key papers, and research hotspots.

III. RESULT AND DISCUSSION

A. *Publication Year*

98,860 references are found by using the search strategy for biofuels in total for the period from 1990 to 2017 in October 2018.

Biofuels research can be roughly divided into two main stages from the perspective of overall distribution since 1990 (Figure 1): Firstly, preliminary research on biofuel research development stage. Before 2006, there were relatively few studies on biofuels around the world, and the number of papers grew moderately, from 239 in 1991 to 1,138 in 2005, with an average annual growth rate of 11.79%, and the growth rate was relatively slow. The second is the rapid development of biofuel research. In 2006-2017, the number of documents increased rapidly, with an average annual growth rate of 20.66%. By 2017, the number of papers reached 12,949, about 7.9 times that of 2006, about 177.4 times that of 1990, which is inseparable from the importance of the deployment of biofuels in major countries around the world.

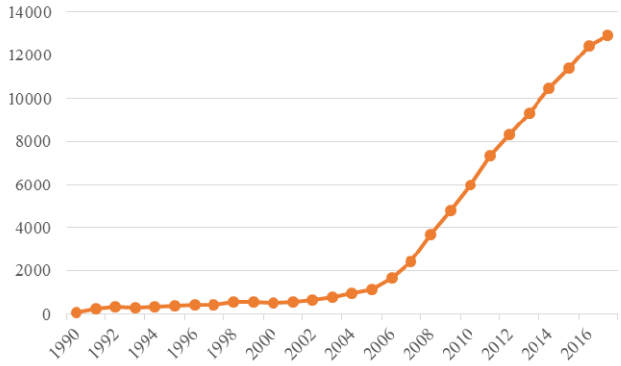

FIGURE I. ANNUAL DISTRIBUTION TREND OF PAPERS IN THE FIELD OF BIOFUELS FROM 1990 TO 2017

B. *Most Publishing Countries/Regions*

The data shows that biofuels involve more than 80 countries/regions. The national distribution map of the main research field in the biofuels field has been obtained by running CiteSpace (Figure 2), there are 23 nodes, and the larger the circle area of the node indicates that the country has a larger amount of publications. The research results show that the USA, China, India, Brazil, Germany are the five biggest contributing countries on biofuels. There is no doubt that the USA is the leader in the field of biofuels, and researchers in the USA account for 20.87% (20,632 papers) of the literature on biofuels. China ranked second, and the number of papers contributed to the field reached 14,411, accounting for 14.58%. India ranked third, reaching 7.31%. Other high-yielding countries include Brazil (5.86%), Germany (4.76%), Japan (3.95%), Spain (3.87%), Italy (3.73%), ENGLAND (3.58%) and Canada (3.31%).

The annual distribution trend of the papers shows the changes in the research intensity of the country in this field. The annual distribution trend of major countries (Figure 3) is mainly divided into two stages. Firstly, the period from 1990 to

2005 was the initial stage of research and development. The number of papers in each country has grown slowly, maintaining a sustained R&D momentum. Secondly, 2006-2017 is a period of rapid development, and the growth rate of literature in major countries is obvious.

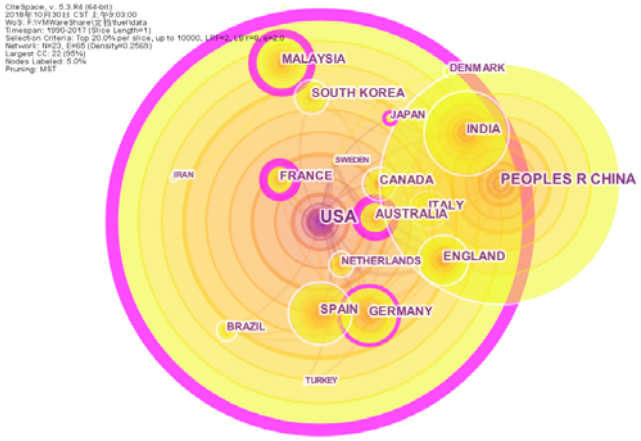

FIGURE II. MAJOR NATIONAL DISTRIBUTION MAPS FOR GLOBAL BIOFUELS

The USA is the most productive country and has the fastest growth rate overall. The number of papers change little in 1990-2005; 2006-2014 is a period of rapid development, and the number of papers increases from 331 in 2006 to 2,148 in 2014, reaching a peak, with an average annual growth rate of 26.6%; 2015-2017 Gradually mature, the number of papers is no longer growing.

China has developed rapidly in the field of biofuels and has recently joined the group of leading countries. The number of papers has been growing rapidly during 1990-2017 and surpass the USA for the first time in 2016, it seems that the trend will continue to grow.

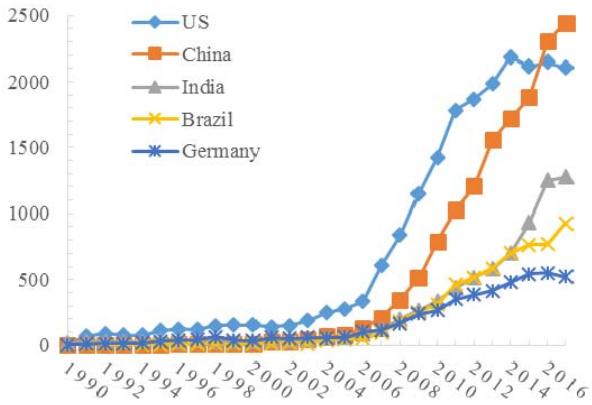

FIGURE III. ANNUAL DISTRIBUTION TRENDS OF BIOFUEL LITERATURE IN MAJOR COUNTRIES

The growth rate of India, Brazil and Germany is relatively slow. The gap between the USA and China is relatively large while compared with the USA and China. The number of Brazil papers has increased rapidly in 2016, and it is very likely to surpass India in the later period from the perspective of growth trend of papers.

C. Most Publishing Institutions

The output of the institution's papers reflects the research strength and the development of the field. Table 1 shows the top 20 institutions according to the number of published papers, some research findings are as follows.

Firstly, there are six institutions in the US, 5 of which are universities. University of California system (1.87%) was the most publishing institution in the US.

Secondly, there are two institutions in China in the top 20 institutions. The Chinese Academy of Sciences (2.35%) is the most publishing institution, and Tsinghua University (0.77%) is located in the eighth places.

Thirdly, there are three institutions in France in Table 1. The CNRS (1.41%) is located in the fourth places, followed by Universite Cote d Azur Comue (1.31%) and Institut National de la Recherche Agronomique (INRA, 0.58%).

These results suggest that research in this area has been well diffused globally with many research centers and institutions of university. It also shows that the research in the field of biofuels in countries like China, France, India, Denmark is relatively concentrated, but there is still a big gap between the R&D and deployment in the USA.

TABLE I. THE MOST PUBLISHING RESEARCH INSTITUTIONS

	Research institutions	Paper numbers	Paper numbers(%)
1	Chinese Academy of Sciences	2323	2.35
2	University of California system	1851	1.87
3	Indian institute of technology system	1421	1.44
4	Centre National de la Recherche Scientifique (CNRS)	1396	1.41
5	Universite Cote d Azur Comue	1298	1.31
6	Council of Scientific Industrial Research (CSIR)	1270	1.28
7	Universidade De Sao Paulo	1296	1.31
8	Tsinghua university	763	0.77
9	Technical University of Denmark	743	0.75
10	University of Illinois System	732	0.74
11	University System of Georgia	706	0.71
12	Consejo Superior de Investigaciones Cientificas (CSIC)	666	0.67
13	Universidade Estadual de Campinas	666	0.67
14	Universiti Malaya	652	0.66
15	Iowa State University	651	0.66
16	University of North Carolina	642	0.65
17	National Renewable Energy Laboratory (NREL)	607	0.61
18	Consiglio Nazionale delle Ricerche (CNR)	604	0.61
19	Lund University	578	0.58
20	Institut National de la Recherche Agronomique (INRA)	572	0.58

The results after the merger of each campus

D. Most Published Subject Area

Each paper in the WOS database is assigned one or more subject heading to enable the subject analysis in a more systematic ways and to highlight the differences between the academic subjects.

The global biofuels research involves more than 170 subject categories, the top 10 are showed in Figure 4. “Energy Fuels” covers more than 31.9% of the 31,550 papers in biofuels, “Biotechnology Applied Microbiology” covers 20.3% of the 20,041 papers. This was followed by “Engineering Chemistry” (17.9%), “Environmental Sciences” (12.0%) and “Agricultural Engineering” (9.0%).

It is especially notable that 51.2% of the papers are published in the area of biofuels as the first two subjects in Figure 4. It seems the selected search terms enabled the location of the most relevant papers for this special issue mostly in the subject fields of “Energy Fuels” and “Biotechnology Applied Microbiology”. These findings are supported by the correlation of these subjects being closely related in biofuels research.

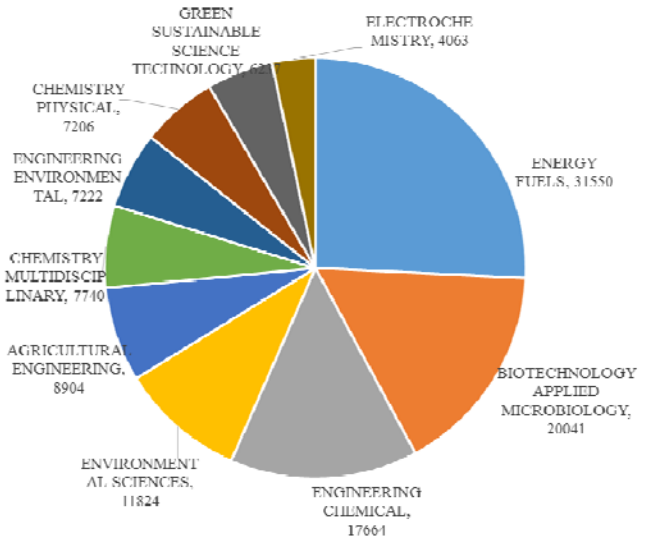

FIGURE IV. THE SUBJECT OF THE PAPERS ON THE BIOFUELS

E. Co-citation Analysis of Papers

A landmark paper on the development of biofuels can be selected in the literature co-citation network, and it can also be considered as the knowledge base in the field of biofuels. Table 2 shows the most co-cited papers on the biofuels.

The data of co-citation frequency can be roughly divided into three levels: The first is the papers with more than 400 co-citations, Chisti (2007, 475 co-citations), who describes the many advantages of microalgae-producing diesel, and discusses the microalgae biodiesel [19]. This paper is cited 4,432 times on Web Of Science, laying a good foundation for the research on microalgae biodiesel; The second is the papers with more than 200 times of co-citations, including Huber (2006, 269 co-citations), Brennan (2010, 261 co-citations), Mata (2010, 255 co-citations), Hu (2008, 245 co-citations), Mohan (2006), Rodolfi (2009, 228 co-citations) [20-25], they mainly focus on biofuels such as microalgae oil, biodiesel. The third is the co-citations of more than 100 times, including Hendriks (2009, 177 co-citations), Bridgwater (2012, 176 co-citations), Kumar (2009, 147 co-citations) [26-28], they mainly study lignocellulosic biomass pretreatment and biomass thermal decomposition. The frequency of citations in these papers is also very high, indicating that these papers have a greater academic influence.

Half-life is one of the indicators for measuring the aging rate of the literature. The longer the paper continues to be cited, the greater the half-life. From the literature half-life point of view, in the 10 papers with higher co-citation frequency, the half-life can be roughly divided into three grades, which are the papers with half-life of 4-6, accounting for 90% of 10 papers. A good foundation for the development of biofuels has been laid because these papers have been cited for a long time.

The data of Citation Bursts is directly proportional to the frequency of citations. The larger the value, the greater the influence of the paper over time. From the data on citation burst of the papers in Table 2, the biggest burst is Huber (31.27), followed by Mohan (29.16), Bridgwater (28.76). Biofuels are one of the key factors in meeting the basic needs of society. It is especially important to sustainably produce transportation fuels without affecting future generations. These studies provide a good reference for the effective and economic use of biofuels at the academic, industrial and government levels.

TABLE II. THE MOST CO-CITED PAPERS ON THE BIOFUELS

	Times co-cited	Burst	Paper reference	Half-life	Times cited
1	475	17.81	Chisti[19]	5	4342
2	269	31.27	Huber[20]	6	4093
3	261	7.81	Brennan[21]	4	557
4	255	-	Mata[22]	4	2112
5	245	9.07	Hu[23]	5	1794
6	235	29.16	Mohan[24]	6	2590
7	228		Rodolfi[25]	4	1338
8	177	11.43	Hendriks[26]	5	1716
9	176	28.76	Bridgwater [27]	3	1478
10	147	8.44	Ragauskas[28]	6	3244

A landmark paper reflects the knowledge base of the research field, the times cited and the time of continuous citation (half-life) also reflect the importance of the papers in the field of biofuels. From the analysis of landmark papers, we can see that the research focus in the field of biofuels changes slowly with time. Different scholars pay different attentions, however, microalgae, lignocellulose, biodiesel, etc. have always been the focus of researchers in the field of biofuels.

F. The Hottest Keywords

The key words are the high concentration of literature research content. And the distribution of keywords in the biofuel field in different time periods reflects the research hotspots in this field. Citation burst can reflect the focus of the

current time period [17-18]. The change of keywords over time can reveal the research trend of the biofuels field from the initial stage to the present. Changes in research hotspots in the field of biofuels are followed in Table 3 by running the CiteSpace keywords co-occurrence function. The highlighted area of each keyword is marked in red, and the data of burst greater than 4 is marked in blue. Some research findings are as follows.

Firstly, from the perspective of the length of burst time, soybean oil has emerged for the longest time, from 1996 to 2011, for 15 years. Fuel ethanol, diesel fuel and rapeseed oil have burst for 12 years, which were hot research topics for long research times. Among them, rapeseed oil is the main raw material of the EU biodiesel, soybean oil is the main raw material of biodiesel in the US, Brazil and other countries, which is also an important reason for the long burst time of rapeseed oil and soybean oil.

And then from the perspective of the data of burst, the emergence of keywords in the field of biofuels can be roughly divided into three levels. Firstly, the research hotspots with a strength of more than 30 are highlighted. Among them, biogas production is the highest, reaching 40.95, followed by vegetable oil (35.48), methane production (34.38), bioethanol production (32.59) and biorefinery (30.20). The second in the range of 20-30, including waste cooking oil (25.47), biofuel cell (25.42), methyl ester (22.88), diesel fuel (21.07), etc. The third is the burst data less than 20, including methanol (17.18), lignocellulosic biomass (14.58), glycerin (11.33) and fuel ethanol (9.35).

The level of keywords with citation burst can show interest of the researchers in biofuels field. The degree of heat will gradually evolve into a research hotspot, and the reasons for the changes in research hotspots are various, including national policies, corporate dynamics, and technical directions.

The analysis of each of the above indicators can explain from various aspects that the research focus in the field of biofuels is slowly shifting over time, and it will provide some reference for relevant policy makers and corporate decision makers.

TABLE III. KEYWORDS WITH STRONGEST CITATION BURST

	Keywords	Burst	Begin	End	1990 - 2017
1	fuel ethanol	9.35	1992	2004	
2	glycerol	11.33	1995	2008	
3	soybean oil	29.63	1996	2011	
4	rapeseed oil	23.36	1996	2008	
5	methyl ester	22.88	1996	2008	
6	diesel fuel	21.07	1996	2008	
7	biofuel cell	25.42	1998	2008	
8	vegetable oil	35.48	2000	2010	
9	transesterification	21.96	2000	2010	
10	methanol	17.18	2000	2008	
11	candida antarctica lipase	13.02	2000	2008	
12	biodiesel	10.52	2000	2004	
13	sunflower oil	7.23	2000	2004	
14	fuel cell	14.94	2001	2008	
15	supercritical methanol	13.74	2001	2008	
16	alternative fuel	5.96	2001	2004	
17	hydrogen production	5.89	2001	2008	
18	fuel production	10.05	2005	2008	
19	hydrolysis	29.54	2010	2014	
20	biogas production	40.96	2015	2017	
21	methane production	34.38	2015	2017	
22	bioethanol production	32.59	2015	2017	
23	biorefinery	30.20	2015	2017	
24	waste cooking oil	25.47	2015	2017	
25	lignocellulosic biomass	14.58	2015	2017	

IV. CONCLUSION

Results of this study relating to the scientometric analysis are based on CiteSpace tool of the papers on biofuels from 1990 to 2017. The main findings are as follows.

Firstly, the biofuels papers are generally on an upward trend, biofuels research can be roughly divided into two main stages. The number of biofuel literature has grown slowly between 1990 and 2006, and the quantity changes are not obvious. During the rapid growth between 2006 and 2017, many scholars pay more and more attention to the research in the field of biofuels.

Secondly, USA, China, India, Brazil, Germany are the five biggest contributing countries on biofuels. The USA ranks first in terms of the number of papers, and other countries have a large gap compared with the USA, which need further investment.

Thirdly, the research on biofuels has been well diffused globally with many research centers and institutions of university. It also shows that the research in the field of biofuels in countries like China, France, India and Denmark is relatively concentrated, but there is still a big gap in the R&D and deployment compared with the USA.

According to the distribution of subjects, the main subjects in the field of biofuels include Energy Fuels, Biotechnology Applied Microbiology, Engineering Chemical, Environmental Sciences and Agricultural Engineering.

Finally, the research hotspots in the field of biofuels has changed from time to time. Research hotspots include fuel ethanol, soybean oil, rapeseed oil, diesel fuel, biodiesel, vegetable oil, and lignocellulosic biomass. At present, bioethanol production and lignocellulosic biomass are important research directions.

In a word, a quantitative analysis of the scientific literature in the field of biofuels is made by using the CiteSpace tool and scientometric analysis. Many results have been found from the country/region, institutions, subject distribution, classic papers, and research hotspots. However, this study also has some shortcomings. For example, when analyzing research hotspots, there is no analysis of the content, but only based on keyword analysis. The next further research will be needed to make in-depth research on institutional cooperation and research hotspots in various countries from a more detailed perspective, and some more interesting findings may be expected in the future.

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