International Trends Analysis for Subject of Hydrogen Production with Water Electrolysis

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Abstracts. Since the 21st century, the domestic and foreign energy structure has been deeply adjusted and therefore the study about hydrogen production with water electrolysis becomes a hotspot. This paper makes bibliometric analysis for related indexes in the field of hydrogen production with water electrolysis, for example, output scale of articles, academic influence, discipline layout, and international cooperation, and compares China's strength with other countries around the world to obtain development trend of the technology in the world, thus formulating related development strategy and discipline policy for the technology and providing useful reference for corporate investment decision-making and researchers in selecting research direction.

1 Introduction

The hydrogen is widely used in the chemical, energy and material industry as the chemical material. In the context of domestic and foreign adjustment in energy structure in the past decades of years, the concept "hydrogen economy" has been improved and the industry chain of hydrogen energy has also been developed gradually. Featured with carbon-free environmental protection and flexibility, the hydrogen production technology with water electrolysis has attracted a lot of attentions [1-4]. In order to accurately obtain development status and potentials and draw a "topographical map" for the development trends, this paper focuses on the hydrogen production with water electrolysis and analyzes international trends and subjects of related studies with literature database and a progressive plane-to-point framework based on the qualitative investigation and expert consultation. The purpose is to analyze domestic and foreign research status and technical hotspot of the field and further demonstrate China's research status in the field of hydrogen production with water electrolysis.

2 Data source and analysis methods

In order to retrieve articles and reviews related to the hydrogen production with water electrolysis, a retrieval strategy [1] is created based on terms provided by the experts. A total of 37726 articles were filtered by literature types ("Article" and "Review") in June 2020. Then the data was analyzed with Excel and Derwent Data Analyzer (DDA).

3 Results

3.1 Analysis for output scale of related studies

3.1.1 Trend analysis

From the view of distribution of SCI articles related to the hydrogen production with water electrolysis by time, as shown in Figure 1, the hydrogen production with water electrolysis was studied initially from 1990s internationally and few studies were developed before 1990. For example, the "water electrolysis and oxygen-hydrogen chain" related achievements were published on Helvetica Chimica Acta in 1921. The annual average number of articles of the field exceeded 1000 after 2013 and increased with growth rate 25%. As a result, the global studies related to the hydrogen production with water electrolysis develop fast and reach a certain scale.

[1]Retrieval strategy: Subject: ("water electroly*" OR "water split*" OR "oxygen evolution reaction" OR "hydrogen evolution reaction") *Index=SCI-EXPANDED Time span=All years*

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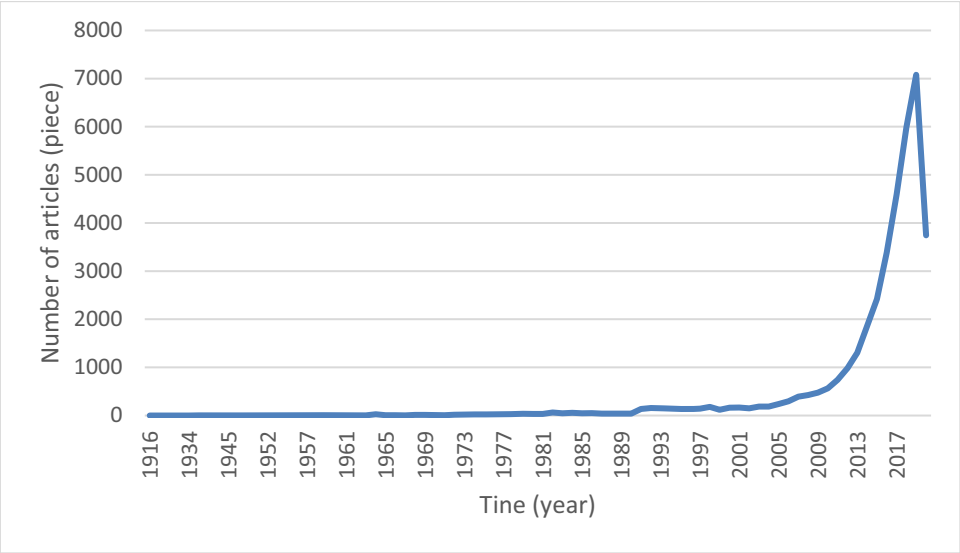

Figure 1 Distribution of SCI articles related to the hydrogen production with water electrolysis by time

3.1.2 National / regional distribution

Over 130 countries and regions around the world have developed studies related to the hydrogen production with water electrolysis. Figure 2 shows the top 20 countries. The top 10 countries include China, USA, Korea, Japan, Germany, India, Australian, UK, Singapore, and Canada, with number of articles over 70% of the total articles related to the hydrogen production with water electrolysis.

From the view of country, China is dominant in the study of this field, of which the number of articles is 34.25% of the total. The number of articles is over 10000 for China and about 6000 for USA; about 2000 for Korea, Japan and Germany; about 1000 for India, Australia, UK, and Singapore. Therefore, there is a large difference between China and other countries.

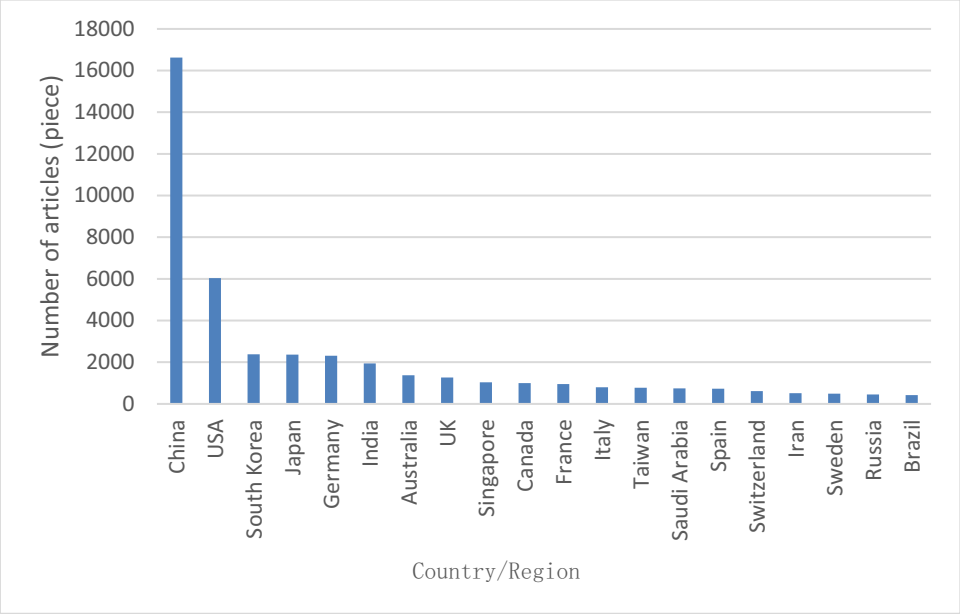

Figure 2 Distribution of SCI articles related to the hydrogen production with water electrolysis by county/region

3.1.3 Institutional distribution

3.1.3.1 Distributions of global institutions

The number of articles related to the hydrogen production with water electrolysis is over 400 for the top 10 institutions around the world, of which 6 institutions have published over 500 related articles, as shown in Table 1. Among the top 10 institutions, except the No. 4 institution from Singapore and No. 9 institution from Japan, all the rest institutions come from China. The top 5 institutions include Chinese Acad Sci, Univ Chinese Acad Sci, Univ Sci & Technol China, Nanyang Technol Univ, and Tianjin Univ, where the number of articles is 2592 for Chinese Acad Sci being the first level of the field; the number of articles is over 500 for Univ Chinese Acad Sci, Univ Sci & Technol China, Nanyang Technol Univ, Tianjin Univ and Tsinghua Univ being the second level of the field; the number of articles is over 400 for Soochow Univ, Beijing Univ Chem Technol, Univ Tokyo, and Jilin Univ being the third level of the field.

Table 1 Distribution of SCI articles related to the hydrogen production with water electrolysis by institution

Ranking	Author's institution	Number of articles	Country (Region)
1	Chinese Acad Sci	2592	China
2	Univ Chinese Acad Sci	801	China
3	Univ Sci & Technol China	755	China
4	Nanyang Technol Univ	664	Singapore
5	Tianjin Univ	601	China
6	Tsinghua Univ	528	China
7	Soochow Univ	479	China
8	Beijing Univ Chem Technol	451	China
9	Univ Tokyo	433	Japan
10	Jilin Univ	422	China

3.1.3.2 Analysis of institutional cooperation

It can be seen from the analysis for cooperation among the top 20 institutions by number of articles in the field that various institutions of each country have developed wide cooperation with domestic and international counterparts, as shown in Figure 3-5.

- For example, the representative Chinese Acad Sci has established close cooperation with Univ Chinese Acad Sci, Univ Sci & Technol China, Tianjin Univ, Tsinghua Univ, Beijing Univ Chem Technol, Univ Tokyo, Harbin Institute of Technology, Nanjing University, Peking University, Sun Yat-sen University, Shandong University, Soochow Univ, and Central South University, where the number of published articles is largest for Univ Chinese Acad Sci and the number of co-published articles of both institutions is 559. Internationally, Chinese Acad Sci cooperates with foreign universities for research, including Nanyang Technol Univ, National University of Singapore, and University of Tokyo, where the number of co-published articles with Nanyang Technol Univ is 23.
- The Nanyang Technol Univ ranks the No. 4 in the number of articles related to the hydrogen production with water electrolysis, and co-published 25 related articles with National University of Singapore. Besides, this institution has established close cooperation with Univ Chinese Acad Sci, Univ Sci & Technol China, Tianjin Univ, Tsinghua Univ, Beijing Univ Chem Technol, Harbin Institute of Technology, Nanjing University, Peking University, Soochow Univ, and University of Tokyo respectively, where the number of co-published articles with Chinese Acad Sci, Tianjin Univ, and Nanyang Technol Univ is 10.

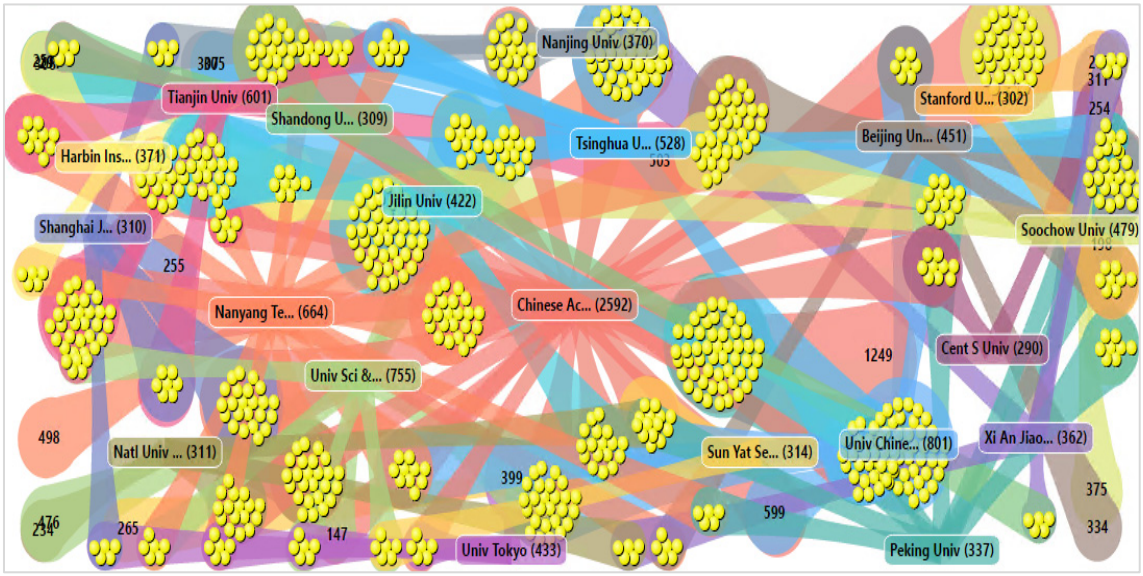

Figure 3 Distribution of institutions with cooperation in the study on hydrogen production with water electrolysis

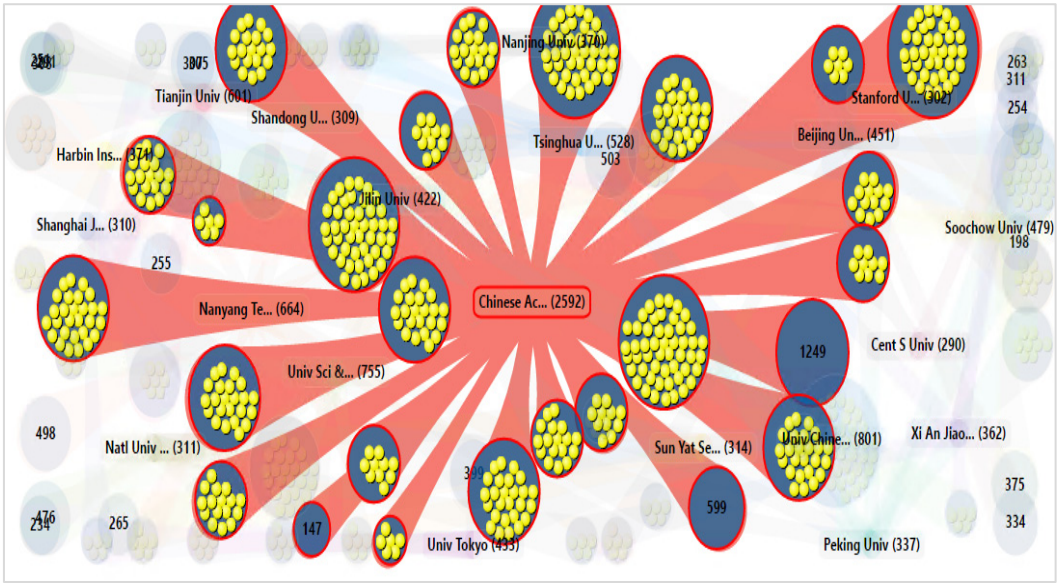

Figure 4 Cooperative institutions of Chinese Acad Sci

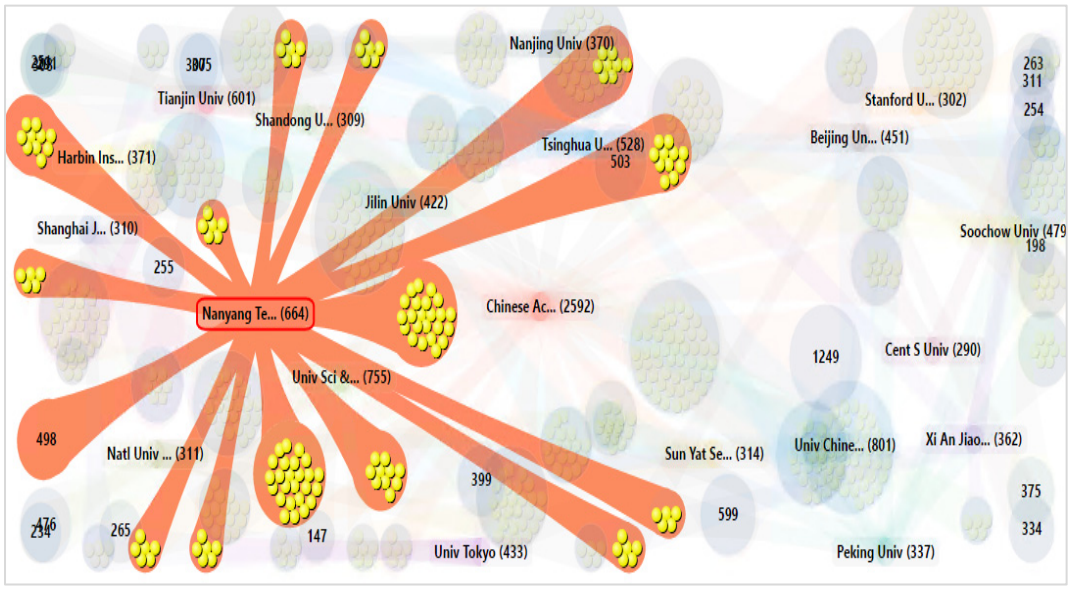

Figure 5 Cooperative institutions of Nanyang Technol Univ

3.2 Analysis of citation frequency by country/region

The citation frequency of articles related to the hydrogen production with water electrolysis around the world is analyzed and accumulated by country to calculate the average citation frequency, as shown in Table 2. The total citation frequency and average citation frequency indicate influence of such articles, where the total citation frequency indicates influence of a country in the field and the average citation frequency indicate the degree of attention to such articles.

From the view of total citation frequency, the top 10 countries include China, USA, Japan, Germany, Australia, Singapore, Korea, UK, Saudi Arabia, Switzerland and Canada. The total citation frequency is 533914 for China, which is larger than other countries. However, the average citation frequency is 32.12 for China, ranking in No. 14, but its influence of articles falls behind the USA, Spain, UK, Switzerland, Italy, Canada, and France. Although USA falls behind China in the number of articles, ranking in No. 2, the average citation frequency is 64.53, ranking in No.1.

Table 2 Citation frequency of SCI articles related to hydrogen production with water electrolysis by country/region

No.	Country/Region	Number of articles	Total citation frequency		Average citation frequency	
			Frequency	Ranking	Frequency	Ranking
1.	China	16621	533914	1	32.12	14

No.	Country/Region	Number of articles	Total citation frequency		Average citation frequency	
			Frequency	Ranking	Frequency	Ranking
2.	USA	6038	389616	2	64.53	1
3.	Korea	2379	59467	7	52.65	5
4.	Japan	2366	121829	3	25.00	16
5.	Germany	2307	83968	4	51.49	6
6.	India	1938	34501	12	32.85	13
7.	Australia	1372	72236	5	36.40	11
8.	UK	1265	51437	8	40.66	7
9.	Singapore	1036	61182	6	17.80	19
10.	Canada	999	39442	11	35.78	12

3.3 Subject analysis

3.3.1 Keywords of subject

Based on retrieved literatures, the keywords are analyzed with the tool TDA to exclude invalid concepts and obtain high-frequency keywords related to the hydrogen production with water electrolysis. The keywords of the subject are divided into four types, including reaction principle of the hydrogen production with water electrolysis, catalysis, electrode material, and structure, to conduct filtering, clustering and correlation analysis and obtain the hotspot subject and correlation between subjects, as shown in Table 3. The reaction principles mainly include water separation, hydrogen evolution reaction, oxygen evolution reaction, oxidation-reduction reaction, density functional theory, electrolytic deposition, and other reactions related to the hydrogen production with water electrolysis. The catalysis mainly includes electrocatalysis, electrocatalyst, photocatalysis, photocatalyst, heterogeneous catalysis, photoelectrocatalysis, and other related concepts. The electrode materials mainly include TiO, CoO, CoP, MoS2, MoC, Pt, Ru, Graphene, IrO, perovskite, etc. The structure is mainly related to nanostructure, nano particle, nano-sheet, nano-composite, nanowire, 2D material, and core-shell structure, etc.

Table 3 Analysis of frequency terms in the field of hydrogen production with water electrolysis

Subject classification	High-frequency keywords (English)	Term frequency	High-frequency keywords (English)	Term frequency
Reaction principle	Water splitting	4703	Photoelectrochemical	651
	Hydrogen evolution reaction	3947	Oxygen evolution	644
	Oxygen evolution reaction	3125	Electrochemistry	584
	Hydrogen evolution	1201	Photoelectrochemical water splitting	559
	Hydrogen production	1147	Electrodeposition	536
	Hydrogen	1070	water oxidation	505
	Oxygen reduction reaction	832	Overall water splitting	467
	Water electrolysis	671	Density functional theory	453
Catalysis	Photocatalysis	2219	Bifunctional electrocatalyst	342
	Electrocatalysis	1938	Bifunctional catalyst	188
	Electrocatalyst	1676	heterogeneous catalysis	155
	Catalysis	497	Cocatalyst	141
	Photoanode	349	Photoelectrocatalysis	115
Electrode material	Metal-organic frameworks	469	Carbon nanotubes	216
	Graphene	390	Thin films	211
	TiO2	344	Molybdenum disulfide	200
	MoS2	317	cobalt	194
	Heterostructure	271	Perovskite	182
	Hematite	259	Platinum	172
	Heterojunction	250	Reduced graphene oxide	168

Subject classification	High-frequency keywords (English)	Term frequency	High-frequency keywords (English)	Term frequency
	Cobalt oxide	248	Molybdenum carbide	153
	nickel	243	Titanium dioxide	153
Structure	nanostructures	369	2D materials	134
	Nanoparticles	308	Nanorods	113
	Nanosheets	247	Nanotubes	112
	Nanocomposites	198	Core-shell structure	111
	nanowires	141	Core-shell	103

4 Conclusions

The hydrogen production with water electrolysis was studied initially from 1990s internationally and few studies were developed before 1990. The annual average number of articles of the field exceeded 1000 after 2013 and increased with growth rate 25%.

Over 130 countries and regions around the world have developed studies related to the hydrogen production with water electrolysis. Various institutions of each country have made wide cooperation, including domestic and international cooperation. China is dominant in the study of this field. Among the top 20 institutions, there are 17 institutions from China. Although China has made a lot of achievements in the field of hydrogen production with water electrolysis, influences of and attentions to the field shall be further strengthened.

The studies related to the hydrogen production with water electrolysis now mainly focus on the reaction, catalytic material, photo-electrochemistry, and structure.

References

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