VI. Environmental & Light and Textile Industries Engineering

1 Engineering research hotspots and engineering research focus

1.1 Development trends of engineering research hotspots

The top 10 engineering research hotspots in the field of environmental and light and textile industries engineering (hereafter referred to as environmental engineering), which includes the subfield of environmental science, environmental engineering, marine science, and climate science are summarized in Table 1.1.1. The in-depth study on traditionally engineering research hotspots includes "The chemical composition of aerosols," "Topographic survey and soil erosion management," "Applications of ligand-based composite adsorbents in water treatment," "Remote sensing inversion techniques and estimation of fluxes for greenhouse gases," "Estimation methods and models of solar radiation," "Assessment and control of greenhouse gas emissions in wastewater treatment plants," and " Analytical techniques of atmospheric CH_4 emissions and sources." The emerging engineering research hotspots include "Arctic sea ice and mid-latitude climate responses," "Regional climate response to global change," and "Hyperspectral unmixing methods." The annual number of core papers for individual research hotspots between 2011 and 2016 are summarized in Table 1.1.2.

(1) The chemical composition of aerosols

Please refer to Section 1.2.1.

(2) Arctic sea ice and mid-latitude climate responses

Please refer to Section 1.2.2.

(3) Hyperspectral unmixing methods

Three-dimensional (3D) hyperspectral images contain both spatial information and a wealth of spectral reflectance information with wide-band coverage, rapid non-destructive, full spectral information content, and other characteristics. Based on the abundant spectral information of hyperspectral images, the effective classification and recognition of imaging objects can be realized by image analysis and pattern recognition algorithms. Therefore, hyperspectral imaging technology has a wide range of applications in agriculture, military, land use, and environmental science. In the field of environmental science, eco-

Table 1.1.1 Top 10 engineering research hotspots in environmental engineering

No.	Engineering research hotspots	Core papers	Citation frequency	Average citation frequency	Mean year	Proportion of consistently cited papers	Patent-cited publications
1	The chemical composition of aerosols	50	2766	55.32	2013.58	24.00%	1
2	Arctic sea ice and mid-latitude climate responses	49	2743	55.98	2014.06	51.00%	0
3	Hyperspectral unmixing methods	45	2924	64.98	2012.64	22.20%	0
4	Topographic survey and soil erosion management	44	1721	39.11	2014.70	40.90%	0
5	Remote sensing inversion techniques and estimation of fluxes for greenhouse gases	41	2503	61.05	2012.95	9.80%	0
6	Assessment and control of greenhouse gas emissions in wastewater treatment plants	42	1484	35.33	2013.45	14.30%	1
7	Applications of ligand-based composite adsorbent in water treatment	40	1393	34.83	2014.08	40.00%	0
8	Estimation methods and models of solar radiation	40	771	19.27	2013.98	7.50%	0
9	Analytical techniques of atmospheric CH_4 emissions and sources	42	1737	41.36	2014.21	16.70%	0
10	Regional climate response to global change	96	3191	33.24	2012.99	10.40%	0

Table 1.1.2 Annual number of core papers belonging to each of the top 10 engineering research hotspots in environmental engineering

No.	Engineering research hotspots	2011	2012	2013	2014	2015	2016
1	The chemical composition of aerosols	5	7	12	10	12	4
2	Arctic sea ice and mid-latitude climate responses	0	8	6	14	17	4
3	Hyperspectral unmixing methods	12	9	8	15	1	0
4	Topographic survey and soil erosion management	0	2	4	8	21	9
5	Remote sensing inversion techniques and estimation of fluxes for greenhouse gases	11	6	7	10	5	2
6	Assessment and control of greenhouse gas emissions in wastewater treatment plants	6	4	11	9	10	2
7	Applications of ligand-based composite adsorbent in water treatment	3	2	10	6	12	7
8	Estimation methods and models of solar radiation	1	2	11	10	15	1
9	Analytical techniques of atmospheric CH_4 emissions and sources	0	5	8	7	17	5
10	Regional climate response to global change	25	16	13	25	11	6

logical/environmental monitoring can be achieved through large-scale hyperspectral data; river water quality and eutrophication status can be evaluated using hyperspectral imaging; and hyperspectral remote sensing data can be used to determine aerosol thickness and composition.

Due to the complex diversity of nature and limited resolution of image sensors, one pixel may have mixed spectra of different materials. Such pixels are called mixed pixels. Mixed pixels greatly reduce the accuracy of the classification of surface features because they cannot be divided into a certain category. In order to solve the problem of mixed pixels, it is necessary to decompose the mixed pixels at the sub-pixel level through unmixing. Unmixing is the use of geometric and statistical methods and models to decompose the proportion of basic components (endmembers) and basic materials (abundance). Although there are many well-established methods, they have their own advantages and disadvantages and their applications differ. The accuracy and stability of the unmixing results have yet to be improved. Therefore, the efficient unmixing of hyperspectral images is still a popular and challenging topic in the applications of hyperspectral imaging technology.

(4) Topographic surveys and soil erosion management

Topographic surveys refer to measuring the projection position and elevation on the horizontal plane of a feature and terrain on the earth’s surface, reducing them to a certain proportion, and drawing topographic maps with symbols and notes. Soil erosion refers to the process of destruction, denudation, transportation, and deposition of soil and soil parent material under the external stress of water, wind, freeze, thaw, or gravity. The key technical issue with this research topic is to develop economical, efficient, and accurate mapping techniques, and apply them to monitoring, evaluation, and management of soil erosion. With respect to topographic surveys, aerial photogrammetry a rapidly developing filed. Notably, the applications of high-precision photographic mapping, light direction and ranging (LIDAR) mapping, and remote sensing (RS), and geographic information system (GIS) technologies based on the unmanned aerial vehicle (UAV) mapping have significantly improved the efficiency and accuracy of mapping. With the maturing UAV technology, high-precision aerial photogrammetry and mapping with UAV have gradually become the foci of current research efforts. This technique has led to the continued development of traditional terrain monitoring research and is widely used in earth science for the modeling, evaluation, and management of soil erosion; terrain modeling; and disaster prevention and mitigation. In the future, the development of economical, efficient, and accurate topographic survey techniques will remain a major research challenge in this field.

(5) Remote sensing inversion techniques and estimation of fluxes for greenhouse gases

Remote sensing technology for atmospheric methane (CH_4) includes space-based and ground-based spectral detection techniques. There are some observation methods for ground-based greenhouse gases, such as Fourier transform spectrometry, grating spectrometry, and LIDAR. For green house gas detection techniques, the tendency of research and development in the future lies towards higher spectral and spatial resolution. Currently, the UK, Germany, France, and the USA are trying to develop a technique based on infrared laser heterodyne spectroscopy. This technique offers many advantages including high spectral resolution, high sensitivity, small volume, and ability to detect carbon dioxide (CO_2) and CH_4 through remote sensing. Therefore, the research focus of this project is to delve deeper into the development of the traditionally available techniques.

(6) Assessment and control of greenhouse gas emissions in wastewater treatment plants

Nitrous oxide (N_2O) is the third largest contributor to global warming after CO_2 and CH_4. The warming effect of N_2O is 350 times that of CO_2. N_2O has a significant impact on ozone depletion and causes serious damage to ecosystems. Wastewater treatment is an important source of N_2O emissions, and the problem of N_2O production in the traditional process of sewage denitrification has attracted the attention of many scholars. It is widely acknowledged that N_2O is the intermediate product or by-product of nitrification and denitrification. The total amount of N_2O emissions has increased with the widespread use of the sewage denitrification process.

This research topic focuses on emissions, reaction mechanisms, temporal variation, control strategies, and factors influencing biological nitrification and denitrification in sewage treatment processes. Key areas of research include the influence of sewage treatment processes and operation modes on N_2O emissions, application of mathematical modeling in the prediction of N_2O emissions during sewage treatment, the effect of pH on N_2O loss and nitrogen removal, and the effect of inorganic carbon on the interaction of microorganisms within the biofilm in the process of nitrification/ammonia oxidation. The influence of different technologies on N_2O emission characteristics in the process of sewage denitrification will continue to remain an important research direction in the future.

(7) Applications of ligand-based composite adsorbent in water treatment

Please refer to Section 1.2.3.

(8) Estimation methods and models of solar radiation

Solar radiation is a major source of energy for physical, biological, and chemical processes on the earth's surface, and also the basic driving force dictating the behavior of the weather and climate. However, due to the restrictions in funds, technology, and environmental conditions, compared to conventional meteorological observation data, such as temperature, humidity, and precipitation, only a few weather stations in China provide solar radiation data, which fails to satisfy research requirements. Different mechanisms and empirical models have been established by researchers from all over the world. Empirical models utilize probability theory and statistical theory as the foundation to build the relationship between solar radiation and meteorological factors, but there are uncertainties in the estimation of solar radiation. Therefore, the research focus of this project is to delve deeper into the development of the traditionally available techniques.

(9) Analytical techniques to determine atmospheric CH_4 emissions and sources

After CO_2, CH_4 is the most important greenhouse gas, and plays a significant role in global warming and chemical destruction of the ozone layer. CH_4 emission sources can be divided into anthropogenic and natural sources. Anthropogenic sources include rice fields, fossil fuel combustion, landfills, and livestock. Natural sources include wetlands, termites, seas, and geological formations. Estimation of global CH_4 sources is based on the observation of CH_4 fluxes but the constraints of time, space, and effects of environmental factors on CH_4 emissions increase the uncertainty of estimations. In the study of biological emission sources, different industries carry out research on emissions from rice fields, wetlands, and livestock but studies on urban emissions are lacking. Therefore, it is necessary to strengthen the research on CH_4 observations and source estimation techniques to obtain more accurate CH_4 source distribution and flux data.

(10) Regional climate response to global change

Please refer to Section 1.2.4.

1.2 Understanding of engineering research focus

1.2.1 The chemical composition of aerosols

China has faced serious atmospheric pollution problems in recent years, especially in autumn and winter. Aerosols in the atmosphere not only influence air quality but also have a significant effect on cloud formation and precipitation. Atmospheric aerosols include primary particles, directly emitted from human activities, and secondary species, converted from gases emitted to the atmosphere. Research on transformation processes, dry and wet deposition, chemical scavenging processes of different types of pollutants in atmospheric aerosols (including cloud, fog, and haze aerosols), and the degradation due to hazardous materials in aerosols to the environment, climate, and human health can provide a theoretical and scientific basis for solving the problem of atmospheric pollution and climate change. Data on the chemical composition of aerosol particles during heavy pollution events in autumn and winter, the composition of oxygenated organic aerosols, and the formation of aerosol chemical species will provide help form the public perception of pollution risks and the government's response.

Many countries in the world consider aerosol pollution as the focus of atmospheric pollution research. Many disciplines with a long-term research direction study the influence of aerosols on health, environment, and climate, and the emission characteristics and secondary transformation characteristics of aerosols.

The review of 50 core papers on aerosol chemical composition revealed that these studies were cited as many as 2766 times, with a per paper citation frequency of 55.32, mostly from 2013 to 2015. Frequently cited papers account for 24.00% of all papers (Table 1.1.1). The number of patents is relatively small. Almost all 50 core studies were conducted in the USA and China, and the citation frequency per paper for both countries is 44.14 and 43.93, respectively (Table 1.2.1). The Chinese Academy of Sciences published 40% of the papers, which were cited866 times (Table 1.2.2). The core papers are mainly about aerosol composition, their physical and chemical properties, and sources, and to a lesser extent, about formation mechanisms, transformation processes, and wet and dry deposition. Studies on aerosol formation mechanisms and transformation processes can not only provide a technical basis for the reduction of aerosol formation but also a scientific basis for efficient government decision-making. Therefore, it is crucial to strengthen research in these two aspects.

In order to control and improve environmental quality without affecting economic development, aerosol chemical composition, formation mechanisms, and transformation processes need in-depth scientific research. Aerosol chemistry has become an important direction with regard to environmental improvement and economic development.

When analyzing the engineering research focus of "The chemical composition of aerosols," the top three countries or regions that published the highest number of core papers are the USA (29), China (29), and Switzerland (14), and the top three countries or regions with highest average citations are Germany (49.13), Spain (48.00), and the USA (44.14) (Table 1.2.1). Among these countries or regions, China and the USA extend the highest level of cooperation to each other, followed by Germany, Switzerland, and England (Figure 1.2.1).

The top three institutions that published the highest number of core papers are the Chinese Academy of Sciences (20), the Paul Scherrer Institute (14), and Aerodyne Research, Inc. (12), and the top three cited institutions per core paper are University of Colorado (82.86), French Alternative Energies and Atomic Energy Commission (CEA) (55.33), and Aerodyne Research, Inc (54.75) (Table 1.2.2). The institutions with the highest number of published papers in China include the Chinese Academy of Sciences, Nanjing University, Nanjing University of Information Engineering, and Peking University (Table 1.2.2).The Chinese Academy of Sciences has a tie-up with Nanjing University of Information Engineering, Nanjing University, and University of California-Davis (Figure 1.2.2).

The major research institutions with regard to the citing core papers include the Chinese Academy of Sciences, Nanjing University, Nanjing University of Information Engineering, and Peking University in China; and Aerodyne Research, Inc. and University of California, Davis in the USA; and the Paul Scherrer Institute in Switzerland (Table 1.2.3 and Table 1.2.4).

1.2.2 Arctic sea ice and mid-latitude climate responses

The Arctic is one of the most sensitive areas to global climate change. The average temperature rise in the last 30 years is twice the rate of global warming, and this phenomenon is known as the "Arctic amplification." Since the 1970s, global temperatures have increased and have had a profound impact on the Arctic, decreasing the Arctic sea ice coverage. By 2012, the area of Arctic sea ice has reduced to less than 40% of the original. With the influence

Table 1.2.1 Major producing countries or regions of core papers on the engineering research focus "The chemical composition of aerosols"

No.	Country/Region	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Consistently cited papers	Patent-cited publications
1	USA	29	58%	1280	52.83%	44.14	2	1
2	China	29	58%	1274	52.58%	43.93	1	1
3	Switzerland	14	28%	602	24.85%	43.00	0	0
4	France	9	18%	330	13.62%	36.67	0	0
5	Germany	8	16%	393	16.22%	49.13	0	0
6	Spain	4	8%	192	7.92%	48.00	0	0
7	England	4	8%	81	3.34%	20.25	0	0
8	The Netherlands	3	6%	124	5.12%	41.33	0	0
9	Norway	3	6%	117	4.83%	39.00	0	0
10	Greece	3	6%	106	4.37%	35.33	0	0

Table 1.2.2 Major producing institutions of core papers on the engineering research focus "The chemical composition of aerosols"

No.	Institution	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Consistently cited papers	Patent-cited publications
1	Chinese Acad Sci	20	40%	866	35.74%	43.30	0	0
2	Paul Scherrer Inst	14	28%	602	24.85%	43.00	0	0
3	Aerodyne Res Inc	12	24%	657	27.12%	54.75	1	0
4	Univ Calif Davis	12	24%	531	21.91%	44.25	1	0
5	Nanjing Univ	10	20%	489	20.18%	48.90	0	0
6	Nanjing Univ Informat Sci & Technol	9	18%	379	15.64%	42.11	0	0
7	Peking Univ	8	16%	365	15.06%	45.63	1	1
8	Univ Colorado	7	14%	580	23.94%	82.86	1	0
9	CEA	6	12%	332	13.70%	55.33	0	0
10	Leibniz Inst Tropospher Res	5	10%	231	9.53%	46.20	0	0

Note: CEA stands for French Alternative Energies and Atomic Energy Commission.

of global warming, internal positive feedback is the key process for the Arctic amplification, which not only leads to polar climate change but also has a significant effect on the global climate, resulting in many extreme weather and climate events. One of these typical events occurred at 11 a.m. on December 30, 2015, when a powerful storm from the Atlantic moved into the Arctic Ocean. At that time, the temperature near the North Pole was approximately the same as that in Beijing. Affected by this event, the Arctic temperature had broken the record of 0 °C, nearly 30 °C higher than the normal temperature in winter. The event also led to extreme cold wave events in China and other mid-latitude regions.

The accelerated melting of sea ice in the Arctic and the dramatic reduction in the sea ice extent will also have an impact on the global economy. Research shows that navigation time in the Arctic Channel is getting longer. By 2030, the airworthiness time may reach 120 d per year. The possible effect on the huge value of commercial shipping has drawn the attention of all stakeholders. In addition, the melting of sea ice has increased the potential for oil exploitation in the Arctic. The rich oil, gas, and mineral resources in the Arctic have attracted attention from many countries or regions. The change in the Arctic sea ice

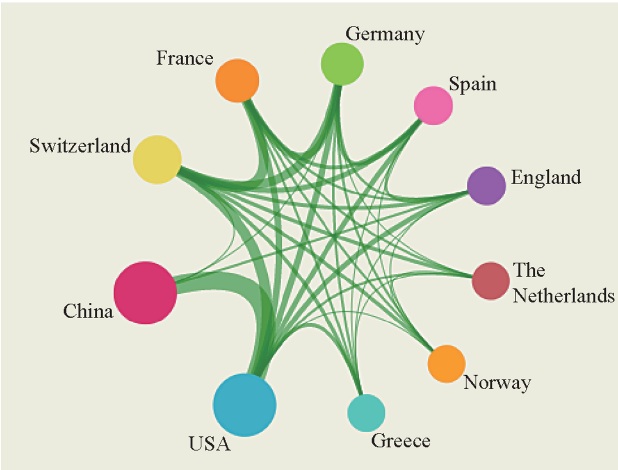


Figure 1.2.1 Collaboration network of the major producing countries or regions of core papers on the engineering research focus "The chemical composition of aerosols"[1]

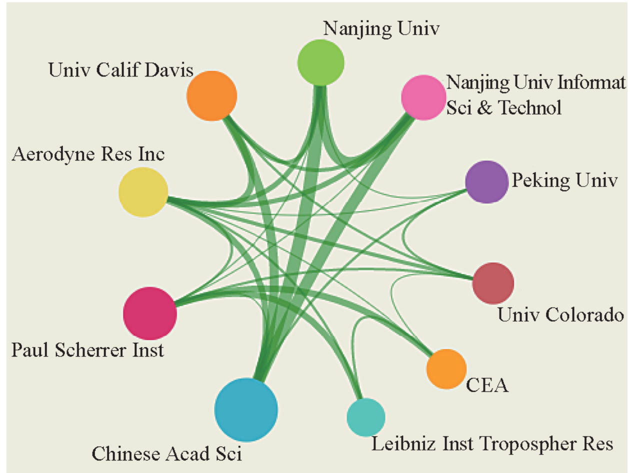


Figure 1.2.2 Collaboration network of the major producing institutions of core papers on the engineering research focus "The chemical composition of aerosols"

Table 1.2.3 Major producing countries or regions of core papers that are cited by core papers on the engineering research focus "The chemical composition of aerosols"

No.	Country/Region	Number of core papers cited by core papers	Proportion	Mean year
1	USA	25	22.32%	2013.88
2	China	23	20.54%	2013.87
3	Switzerland	14	12.50%	2013.57
4	France	9	8.04%	2013.78
5	Germany	8	7.14%	2013.63
6	England	4	3.57%	2015.00
7	Spain	4	3.57%	2014.00
8	The Netherlands	3	2.68%	2012.67
9	Norway	3	2.68%	2013.33
10	Greece	3	2.68%	2013.67

extent is not only a climate issue but has also brought about a new focus on engineering exploitation techniques in the 21st century.

Although the Arctic sea ice covers only a small part of the global ocean, it plays an important role in Earth's weather and climate. Sea ice has relatively high albedo, which forms a feedback effect in the global climate system. At the same time, the thermal conductivity of sea ice is very low and can block atmospheric heat and water vapor exchange in sea-ice-covered areas, affecting the atmospheric circulation system and weather conditions, leading to large-scale extreme weather events. Therefore, the study of the interaction between the Arctic sea ice reduction and the atmospheric circulation in the Northern Hemisphere is very important and necessary to reveal the role of Arctic sea ice in climate change. One of the important missions of Arctic science is to investigate the mechanisms underlying these positive feedback processes. Major scientific problems related to Arctic amplification mainly concern atmosphere-ice-sea interactions, sea ice being the most active factor. To solve these problems, the changes in the structure of the sea ice should be determined,

[1] In the figure, the nodes refer to the countries or regions, the size of the nodes refers to number of papers, the connecting line between nodes refers to papers published based on research cooperation, and the thickness of the connecting line indicates the number of papers based on research cooperation. These are the same in full text.

Table 1.2.4 Major producing institutions of core papers that are cited by core papers on the engineering research focus "The chemical composition of aerosols"

No.	Institution	Number of core papers cited by core papers	Proportion	Mean year
1	Chinese Acad Sci	16	6.96%	2014.13
2	Paul Scherrer Inst	14	6.09%	2013.57
3	Aerodyne Res Inc	9	3.91%	2014.22
4	Univ Calif Davis	9	3.91%	2014.22
5	Nanjing Univ Informat Sci & Technol	9	3.91%	2014.22
6	Nanjing Univ	9	3.91%	2014.22
7	CEA	6	2.61%	2013.50
8	Peking Univ	6	2.61%	2013.33
9	Leibniz Inst Tropospher Res	5	2.17%	2013.60
10	Univ Colorado	5	2.17%	2013.60

and thermodynamic characteristics of the change should be quantitatively expressed. Thus, factors such as melting pool, lateral melting, and snow and sea ice drift should be fully considered. The ocean is a key source of energy for changes in the Arctic. In winter, sea ice spreads over the ocean, creating an insulating layer that prevents much heat from escaping from the ocean to warm the air. Ocean currents also bring heat from warmer regions into the Arctic Ocean. Therefore, we need to understand the distribution of ocean heat flux (the mechanism of energy storage and release) and the effect of the changes in freshwater and thermocline structure on sea-air coupling.

The rapid changes in the Arctic sea ice extent have attracted significant attention. Implemented research projects include WCRP (World Climate Research Programme), CliC (Climate and Cryosphere), ACSYS (Arctic Climate System Study), SHEBA (Surface Heat Budget of the Arctic Ocean Experiment), LOIRA (Land-Ocean Interactions in the Russian Arctic), JWACS (Joint Western Arctic Climate Study), DAMOCLES (Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies), and NABOS (Nansen and Amundsen Basins Observational System). These projects have focused on the Arctic and global climate change using on-site observations and numerical simulations. The response to the changes in sea ice extent on climate change was investigated through the research and development of the atmosphere-ocean-sea-ice coupling model. Among them, launched in 1993, ACSYS, one of the important subprograms of WCRP, mainly studies the effect of the Arctic climate change (primarily reflected in the reduction of sea ice) on the global environmental system.

The understanding of Arctic sea ice and atmospheric-ocean interactions has not been translated into the physical essence of sea ice change. The results of the existing studies attributed the changes in Arctic sea ice to global climate change and positive feedback processes it caused in the Arctic. The studies suggest that these processes make the ocean absorb more heat and strengthen the interactions among the atmosphere, ocean, and ice, and result in further decreases in sea icecover. However, it is not easy to determine these processes because most of them involve the physical processes of ocean and sea ice changes, which are not clearly understood. As a result, research on changes in the Arctic has not progressed much in recent years. In order to improve this situation, it is necessary to study the physical processes in the Arctic in depth, focusing on new and degenerative processes caused by Arctic warming. In addition, studying the physical processes based only on the assimilation data and reanalysis is far from sufficient. It is necessary to carry out large-scale field observations to obtain on-site data from the Arctic to understand the physical processes.

The analysis of the core papers and the main producing countries or regions (Table 1.2.5) shows that the USA, England, and Germany are the top three countries or regions with regard to the number of papers published on this research topic, followed by Australia, Japan, Korea, China, Norway, Switzerland, and Finland. The USA has published 61.22% of the core papers, indicating that the USA has a greater research interest in this field. England comes second, accounting for 30.61% of all papers on the subject. The total citation reflects the subsequent effects of the study; the ranking is consistent with the proportion of core papers by country or region. Although China's rank with regard to the total number of papers on the index is not the highest, the average citation of each paper from China ranks first (157.00 times).

The University of Exeter in England and the National Center for Atmospheric Research and Rutgers State University in the USA are the top three institutions publishing core papers, followed by the University of Melbourne (Australia), the National Oceanic and Atmospheric Administration (the USA), the University of Colorado (the USA), the Potsdam Institute for Climate Impact (Germany), the Colorado State University (the USA), the National Institute of Polar Research (Japan), and the Atmospheric and Environmental Research, Inc. (the USA) (Table 1.2.6). Six institutions out of ten are located in the USA as well. Chinese research institutions do not appear within the top 10 rankings, indicating that most research activities are conducted by other institutions.

The main research partnerships are among the USA, England, Germany, and Australia, while China has a relationship only with the USA (Figure 1.2.3). Except for the National Institute of Polar Research (Japan), there is extensive communication among the top 10 institutions, which illustrates the importance of cooperation and communication in scientific research on the Arctic (Figure 1.2.4).

Arctic sea ice reduction has a major impact on the climate of mid-latitude regions, including the USA, Europe, and China. Its impact on the USA has been thoroughly researched, and studies of the impact on Europe have also yielded some accomplishments. China's studies in the Arctic began in the 1990s; despite starting late, the activities have developed rapidly.

China established the Arctic Yellow River Station in 2004 and carried out seven Arctic scientific surveys in 1999, 2003, 2008, 2010, 2012, 2014, and 2016. In response to worldwide attention on the exploitation of the Arctic, China's research in the Arctic has developed rapidly.

On December 10, 2013, ten Arctic research institutes from China and the Nordic countries (Iceland, Denmark, Finland, Norway, and Sweden) signed an agreement in Shanghai and announced the establishment of the China-Nordic Arctic Research Center (CNARC).

On December 20, 2016, construction of an icebreaker was started in the Jiangnan Shipyard. It is the first independently built Chinese polar scientific expedition icebreaker. The ship is expected to be completed in 2019 and then become part of a polar expedition fleet with the *Snow Dragon*. With these developments, China's abilities with regard to polar oceanographic surveys and support have improved.

In December 2016, China launched the first fully owned overseas satellite ground station near the North Pole in Kiruna, Sweden. With this station, China has made great technical progress and is able to access remote sensing data much more quickly. This development is of vital significance for rapid response to natural disasters and will promote international cooperation in this field.

The literature analysis shows that the number of core papers published by Chinese scientists in this research field rank among the top 10 (seventh), but most of them have been published by different research institutions; therefore, China fails to enter the top 10 list of the core paper producing institutions. The top 10 countries or regions and institutions ranked by the number of producing citing core papers on sea ice change are listed in Table 1.2.7 and Table 1.2.8. The USA, England, and Germany and their research institutions appear at the top of the list, while China is missing from the list (Table 1.2.7 and Table 1.2.8). China's two core papers (Table 1.2.5) focuses on the relationships between Arctic sea ice ablation and winter snowfall and between Arctic sea ice ablation and extreme weather events in the Northern Hemisphere. The main research institutions in China are the Chinese Academy of Sciences and Beijing Normal University.

In general, the USA, Germany, and England have published the largest number of core papers. Although the number of core papers published by Chinese scientists ranks within the top 10 and the papers are cited frequently (Table 1.2.5), there is no leading research institution on the list. Korea and Japan also ranked among the top 10 in several lists (Table 1.2.5, Table 1.2.6, and Table 1.2.8) given their close attention to research in this field. China's research focuses mainly on the impact of Arctic sea ice on East Asia and China's climate rather than the global climate. Therefore, even though more papers have been published, the number of publications that cited the papers about sea ice change is relatively small.

Moreover, there is close cooperation among the top-ranked countries or regions, which shows the importance of international cooperation in research in the Arctic. The

Table 1.2.5 Major producing countries or regions of core papers on the engineering research focus "Arctic sea ice and mid-latitude climate responses"

No.	Country/Region	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Consistently cited papers	Patent-cited publications
1	USA	30	61.22%	1839	74.70%	61.30	6	0
2	England	15	30.61%	674	27.38%	44.93	3	0
3	Germany	9	18.37%	480	19.50%	53.33	1	0
4	Australia	5	10.20%	343	13.93%	68.60	1	0
5	Japan	5	10.20%	188	7.64%	37.60	1	0
6	Korea	3	6.12%	111	4.51%	37.00	1	0
7	China	2	4.08%	314	12.75%	157.00	1	0
8	Norway	2	4.08%	48	1.95%	24.00	0	0
9	Switzerland	2	4.08%	34	1.38%	17.00	0	0
10	Finland	1	2.04%	33	1.34%	33.00	0	0

Table 1.2.6 Major producing institutions of core papers on the engineering research focus "Arctic sea ice and mid-latitude climate responses"

No.	Institution	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Consistently cited papers	Patent-cited publications
1	Univ Exeter	9	18.37%	526	21.36%	58.44	2	0
2	Natl Ctr Atmospher Res	7	14.29%	235	9.55%	33.57	0	0
3	Rutgers State Univ	5	10.20%	665	27.01%	133.00	2	0
4	Univ Melbourne	5	10.20%	343	13.93%	68.60	1	0
5	NOAA	5	10.20%	109	4.43%	21.80	1	0
6	Univ Colorado	5	10.20%	85	3.45%	17.00	1	0
7	Potsdam Inst Climate Impact Res	4	8.16%	291	11.82%	72.75	1	0
8	Colorado State Univ	4	8.16%	187	7.60%	46.75	0	0
9	Natl Inst Polar Res	4	8.16%	119	4.83%	29.75	0	0
10	Atmospher & Environm Res Inc	3	6.12%	301	12.23%	100.33	1	0

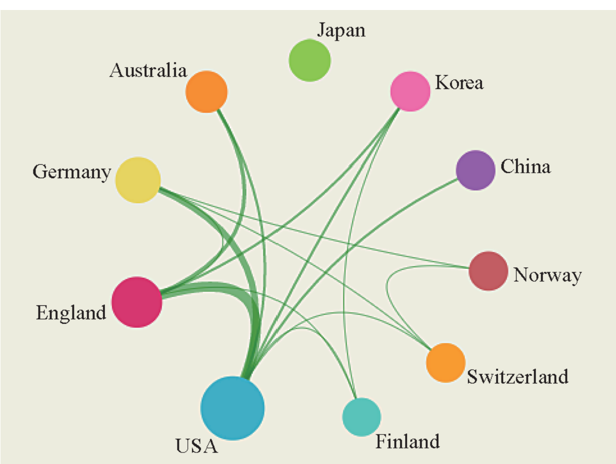


Figure 1.2.3 Collaboration network of the major producing countries or regions of core papers on the engineering research focus "Arctic sea ice and mid-latitude climate responses"

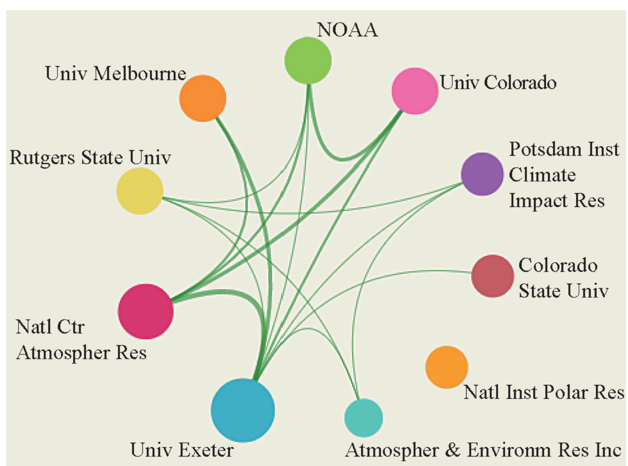


Figure 1.2.4 Collaboration network of the major producing institutions of core papers on the engineering research focus "Arctic sea ice and mid-latitude climate responses"

Table 1.2.7 Major producing countries or regions of core papers that are cited by core papers on the engineering research focus “Arctic sea ice and mid-latitude climate responses”

No.	Country/Region	Number of core papers cited by core papers	Proportion	Mean year
1	USA	28	41.18%	2014.14
2	England	12	17.65%	2014.58
3	Germany	8	11.76%	2013.75
4	Japan	5	7.35%	2014.20
5	Australia	4	5.88%	2013.50
6	Korea	3	4.41%	2014.67
7	Switzerland	2	2.94%	2015.50
8	Canada	1	1.47%	2016.00
9	Finland	1	1.47%	2015.00
10	Sweden	1	1.47%	2015.00

Table 1.2.8 Major producing institutions of core papers that are cited by core papers on the engineering research focus “Arctic sea ice and mid-latitude climate responses”

No.	Institution	Number of core papers cited by core papers	Proportion	Mean year
1	Univ Exeter	8	6.84%	2014.50
2	Natl Ctr Atmospher Res	7	5.98%	2014.71
3	NOAA	5	4.27%	2015.20
4	Potsdam Inst Climate Impact Res	5	4.27%	2013.80
5	Rutgers State Univ	5	4.27%	2013.80
6	Univ Colorado	5	4.27%	2014.60
7	Colorado State Univ	4	3.42%	2014.25
8	Univ Melbourne	4	3.42%	2013.50
9	Natl Inst Polar Res	4	3.42%	2014.75
10	Korea Polar Res Inst	3	2.56%	2014.67

Chinese government has recently set the goal of becoming a maritime power. Maintaining and expanding interests in the Arctic is an important part of becoming a maritime power. It requires serious scientific research and surveys in the Arctic as well as abundant funds. China needs to build and consolidate bilateral and multilateral international platforms to promote multi-level communication and cooperation in this field.

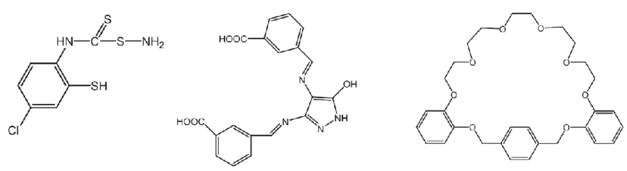
1.2.3 Applications of ligand-based composite adsorbent in water treatment

Heavy metals are a group of harmful pollutants in the water environment. Due to their persistence and bio-enrichment and bio-accumulation effects, heavy metals pose threats to the environmental and ecological health. Wastewater discharge containing excess heavy metals into surface water or groundwater leads to pollution in the aquatic and soil environments. Through intake and enrichment by plants and animals, heavy metals could be transferred to the human body via water and food, which increases cancer risks. With growing concerns over public health and the ecological threat induced by heavy metals, the maximum allowable regulated contaminant levels for heavy metals in wastewater, drinking water, and natural waters are becoming increasingly stringent worldwide. Such stringency in standards and water shortages underscore the need for the complete removal of heavy metals from water to ensure drinking water safety, protect the aquatic/ecological environment, and improve water utilization efficiency. Adsorption is one of the most efficient technologies to remove heavy metals from water due to its easy operation and low cost. Moreover, various types of reactors can be designed for adsorption to fulfill the practical demand of different scales, from point-of-use (POU) to full-scale applications.

The development of efficient adsorbents is the key to improving adsorption technologies. Complexation is an important type of specific interaction between heavy metals and organic/inorganic ligands. Through the immobilization of ligands onto adsorbents, various ligand-based composite adsorbents have been developed for selective removal of heavy metals from water. On the one hand, efforts have been made to design and synthesize ligands with high selectivity and high affinity for heavy metals. On the other hand, the adsorbents of multiple functions, such as optical sensing, photocatalysis, and antibacterial features, have been developed.

This research focus covered 40 core papers, which have been cited 34.83 times on average; 40.00% of these are consistently cited papers, showing a rising trend. Thus, these articles have a high impact on the related studies. The average publication year of these articles is 2014.08, indicating rapid citation and impact (Table 1.1.1). The numbers of articles containing the topics "ligand," "composite," "conjugate," "fibrous," and "complex" are 28, 23, 18, 18, and 14, respectively. These articles are mostly on the removal of Cu(II), Pb(II), Cs(I), As(V), Pd(II), Ce(III), Co(II), and the lanthanides. Eight and seven core papers refer to the removal of Cu(II) and Pb(II), respectively. Five core papers study the removal of Cs(I), which is radioactive and present in nuclear waste. In addition, several core papers are about the multi-functional materials for separation of heavy metals, optical sensing, antibacterial features, and photocatalysis. The ligands of interest in those core papers mainly include N-substituted heterocycles, S-containing ligands, azo-based ligands, Schiff bases, crown ethers, and molybdophosphates. Most ligands are of complicated structures; three typical structures are listed in Figure 1.2.5. Ligands (a) and (b) could possess visible light absorption or fluorescence feature due to their large conjugation structures. Ligand (c) could selectively sequester Cs(I) through size effect. These ligands are immobilized on hosts such as mesoporous silica to synthesize the ligand-based composites as adsorbents, which can be separated from water after adsorption.

Among the 40 core papers, 25 (62.5%) were published in *Chemical Engineering Journal*, indicating the popularity of this topic. Japan contributed the largest number of articles (31 core papers) within the list of major countries or regions (Table 1.2.9), accounting for 77.50% of core papers and 85.49% of total citations. Saudi Arabia, Egypt, Bangladesh, and India contributed 5 to 12 core papers, and the other countries or regions published only one core paper. Among the top 10 institutions (Table 1.2.10), Japan Atomic Energy Agency ranked first with 27 core papers, which



(a) (b) (c)

Figure 1.2.5 Three typical structures of ligands studied in the core papers regarding ligand-based composite adsorbents

Table 1.2.9 Major producing countries or regions of core papers on the engineering research focus "Applications of ligand-based composite adsorbent in water treatment"

No.	Country/Region	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Consistently cited papers	Patent-cited publications
1	Japan	31	77.50%	1102	85.49%	35.55	3	0
2	Saudi Arabia	12	30.00%	285	22.11%	23.75	2	0
3	Egypt	6	15.00%	248	19.24%	41.33	0	0
4	Bangladesh	6	15.00%	186	14.43%	31.00	0	0
5	India	5	12.50%	96	7.45%	19.20	1	0
6	Korea	1	2.50%	69	5.35%	69.00	0	0
7	Australia	1	2.50%	25	1.94%	25.00	0	0
8	Spain	1	2.50%	10	0.78%	10.00	0	0
9	China	1	2.50%	4	0.31%	4.00	0	0

Table 1.2.10 Major producing institutions of core papers on the engineering research focus "Applications of ligand-based composite adsorbent in water treatment"

No.	Institution	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Consistently cited papers	Patent-cited publications
1	Japan Atomic Energy Agency	27	67.50%	971	75.33%	35.96	3	0
2	King Saud Univ	12	30.00%	285	22.11%	23.75	2	0
3	Natl Inst Mat Sci	8	20.00%	416	32.27%	52.00	1	0
4	Kumamoto Univ	5	12.50%	248	19.24%	49.60	0	0
5	Independent Univ	4	10.00%	127	9.85%	31.75	0	0
6	Shaheed Ziaur Rahman Med Coll	4	10.00%	78	6.05%	19.50	0	0
7	Shoolini Univ	4	10.00%	72	5.59%	18.00	0	0
8	Suez Univ	3	7.50%	93	7.21%	31.00	0	0
9	Waseda Univ	3	7.50%	89	6.90%	29.67	0	0
10	Univ Dhaka	2	5.00%	108	8.38%	54.00	0	0

accounted for 67.5% of core papers and 75.33% of total citations. King Saud University and National Institute for Materials Science contributed 12 and 8 core papers, respectively. The other institutions in Table 1.2.10 contributed 2 to 5 core papers.

A total of 30 out of the 40 core papers were contributed by M. R. Awual from Japan Atomic Energy Agency. M. R. Awual published 26 of these as the first author and corresponding author, two as the corresponding author, and two as co-author. The 30 core papers have been cited 1176 times, amounting to 39.20 times per article on average. Moreover, among the 436 papers citing the above 30 core papers, 49 were from the same author and 387 were published by other researchers, indicating the leading position of author M. R. Awual in the present research focus. Among the 12 core journal articles of other corresponding authors, four were contributed by M. Naushad from King Saud University, three by S. A. El-Safty from the National Institute of Materials Sciences in Japan (of which two were with M. R. Awual as co-author), and three were contributed by D. Pathania from Shoolini University in India. Yuxiang Li from Southwest University of Science and Technology in China and A. Kumar from Shoolini University in India both contributed one core papers. It can be seen from their cooperative history (not limited to the core papers) that M. Naushad and M. R. Awual cooperatively published 11 articles in 2015—2016, S. A. El-Safty and M. R. Awual cooperatively published 10 articles in 2011—2013, while D. Pathania and M. Naushad cooperatively published 17 articles in 2014—2017. The cooperative networks are shown in Figure 1.2.6 and Figure 1.2.7. The role of the other countries or regions and institutions in the figures is mainly limited to participating in the above core papers. The distribution of the main contributing countries or regions (Table 1.2.11) and institutions (Table 1.2.12) with regard to the papers citing the above core papers is similar to those of the core papers (Table 1.2.9 and Table 1.2.10), indicating the citations are primarily generated by the main contributing research groups, and the present research focus is being led by the institutions listed in this paragraph.

China contributed one core papers, the corresponding author being Prof. Yuxiang Li from Southwest University of Science and Technology. The paper focused on the removal of cesium (Cs) using a composite ion exchanger of silica matrix impregnated with ammonium molybdophosphate. According to the results of the literature search, hundreds of articles from China have been published on topics related to this engineering research focus. However, the number of citations is relatively lower than the 40 core papers, suggesting the possibly lower popularity of this engineering research focus. Nevertheless, the 40 core papers were selected through data mining using the keyword "clustering analysis," which is subject to limitations of whether the related papers belong to this research focus. On the other hand, various ion-exchanger-based nanocomposites and chelating resins have been developed by Chinese institutions to remove heavy metals from water. Such composite materials have appropriate hydrodynamic properties for practical applications and

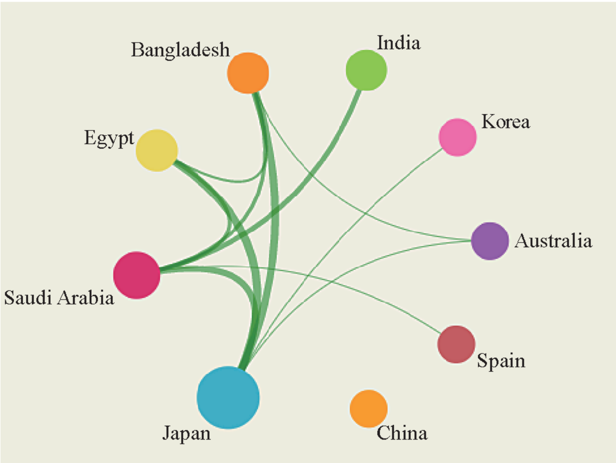


Figure 1.2.6 Collaboration network of the major producing countries or regions of core papers on the engineering research focus “Applications of ligand-based composite adsorbent in water treatment”

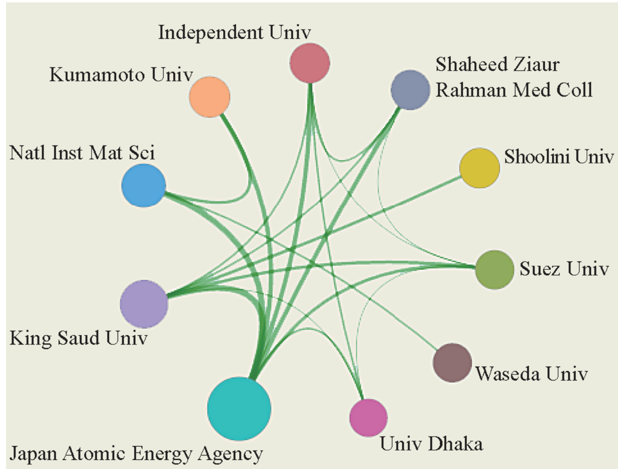


Figure 1.2.7 Collaboration network of the major producing institutions of core papers on the engineering research focus “Applications of ligand-based composite adsorbent in water treatment”

Table 1.2.11 Major producing countries or regions of core papers that are cited by core papers on the engineering research focus “Applications of ligand-based composite adsorbent in water treatment”

No.	Country/Region	Number of core papers cited by core papers	Proportion	Mean year
1	Japan	42	50.00%	2014.19
2	Bangladesh	17	20.24%	2014.65
3	Egypt	10	11.90%	2014.00
4	Saudi Arabia	9	10.71%	2014.89
5	India	3	3.57%	2014.67
6	Australia	2	2.38%	2015.00
7	Korea	1	1.19%	2011.00

Table 1.2.12 Major producing institutions of core papers that are cited by core papers on the engineering research focus “Applications of ligand-based composite adsorbent in water treatment”

No.	Institution	Number of core papers cited by core papers	Proportion	Mean year
1	Japan Atomic Energy Agency	40	30.77%	2014.35
2	Shaheed Ziaur Rahman Med Coll	12	9.23%	2014.83
3	King Saud Univ	9	6.92%	2014.89
4	Independent Univ	8	6.15%	2014.75
5	Kumamoto Univ	7	5.38%	2012.29
6	Suez Univ	4	3.08%	2014.75
7	Univ Dhaka	4	3.08%	2014.25
8	Natl Inst Mat Sci	3	2.31%	2011.67
9	Shoolini Univ	3	2.31%	2014.67
10	Sohag Univ	3	2.31%	2014.00

some of them have been produced at the full scale. Technologies of in-depth removal and resource reuse of heavy metals based on the above composite materials have also been developed and industrially applied. However, the research articles concerning the above composite materials were not included in the selected core journal articles of the research focus due to the absence of keywords such as "ligand" and "conjugate." Nevertheless, the research articles from China concerning the composite materials for heavy metal removal are influential in a broad sense.

The number of the core papers containing the word "nano" in the topic reached 24, indicating that nanotechnology is an important future direction for the removal of heavy metals in water treatment. However, there is still a long way to go from the laboratory-scale research to industrial application of nanomaterials due to the diversity of materials, target contaminants, and treatment objectives. To achieve the applicability of the nanomaterials in water treatment, the development and structural tuning of the applicable environmental nanocomposites, performance and mechanisms of contaminant purification, development of appropriate reactors, and integration with other technologies are worthy of systematic investigations. It is also essential to consider the interdisciplinary subjects such as nanomaterial sciences, surface analysis, and mathematical modeling.

1.2.4 Regional climate response to global change

The response of regional climate to global change is closely related to human life and social development. These issues are also the focus of scientific research on climate change. Research on regional climate response to global change is conducted using a regional climate model with higher resolution, satellite remote sensing methods, numerical simulations, and theoretical analysis.

Regarding the research focus of "Regional climate response to global change," the top three countries or regions that published the largest number of core papers are China (45), Germany (30), and the USA (29). The largest number of average citations belongs to the Netherlands (50.00), France (41.93), and Sweden (41.00) (Table 1.2.13). With regard to the number of most citing papers, China ranks first (32), followed by Germany (24) and the USA (21). China also ranked first in the proportion of citing core papers (Table 1.2.15).

The top three institutions issuing the largest number of core papers are Chinese Academy of Sciences (27), Lanzhou University (12), and Senckenberg Research Institute (11). The largest number of average citation belong to Natural History Museum (41.20), University of Quebec (41.00), and Senckenberg Research Institute (39.36) (Table 1.2.14). With regard to the main output institutions of citing core papers, the Chinese Academy of Sciences ranked first (18), followed by University of Bonn (9) and Lanzhou University (8) (Table 1.2.16).

In summary, China always ranks first in the number and the main output institutions of citing core papers for this research focus. According to Table 1.2.13, the average citation is 35.70 but the corresponding number for China is 28.33.

Table 1.2.13 Major producing countries or regions of core papers on the engineering research focus "Regional climate response to global change"

No.	Country/Region	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Consistently cited papers	Patent-cited publications
1	China	45	46.88%	1275	44.52%	28.33	3	0
2	Germany	30	31.25%	1060	37.01%	35.33	2	0
3	USA	29	30.21%	799	27.90%	27.55	2	0
4	Italy	17	17.71%	624	21.79%	36.71	2	0
5	England	16	16.67%	441	15.40%	27.56	0	0
6	France	14	14.58%	587	20.50%	41.93	2	0
7	Sweden	9	9.38%	369	12.88%	41.00	1	0
8	Canada	9	9.38%	332	11.59%	36.89	0	0
9	Switzerland	9	9.38%	285	9.95%	31.67	0	0
10	The Netherlands	8	8.33%	400	13.97%	50.00	0	0

Table 1.2.14 Major producing institutions of core papers on the engineering research focus "Regional climate response to global change"

No.	Institution	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Consistently cited papers	Patent-cited publications
1	Chinese Acad Sci	27	28.13%	732	25.56%	27.11	3	0
2	Lanzhou Univ	12	12.50%	356	12.43%	29.67	1	0
3	Senckenberg Res Inst	11	11.46%	433	15.12%	39.36	1	0
4	Nat Hist Museum	10	10.42%	412	14.39%	41.20	0	0
5	Univ Bonn	10	10.42%	356	12.43%	35.60	1	0
6	Nanjing Univ	8	8.33%	168	5.87%	21.00	0	0
7	Univ Helsinki	7	7.29%	255	8.90%	36.43	0	0
8	E Tennessee State Univ	7	7.29%	214	7.47%	30.57	1	0
9	Open Univ	7	7.29%	137	4.78%	19.57	0	0
10	Univ Quebec	6	6.25%	246	8.59%	41.00	0	0

Table 1.2.15 Major producing countries or regions of core papers that are cited by core papers on the engineering research focus "Regional climate response to global change"

No.	Country/Region	Number of core papers cited by core papers	Proportion	Mean year
1	China	32	16.08%	2013.19
2	Germany	24	12.06%	2013.00
3	USA	21	10.55%	2013.81
4	Italy	12	6.03%	2014.08
5	France	10	5.03%	2013.20
6	Switzerland	9	4.52%	2013.67
7	England	9	4.52%	2014.11
8	Canada	7	3.52%	2013.29
9	The Netherlands	7	3.52%	2012.57
10	Sweden	6	3.02%	2014.00

Table 1.2.16 Major producing institutions of core papers that are cited by core papers on the engineering research focus "Regional climate response to global change"

No.	Institution	Number of core papers cited by core papers	Proportion	Mean year
1	Chinese Acad Sci	18	5.68%	2013.39
2	Univ Bonn	9	2.84%	2011.78
3	Lanzhou Univ	8	2.52%	2013.25
4	Senckenberg Res Inst	7	2.21%	2011.86
5	Nanjing Univ	6	1.89%	2013.83
6	Nat Hist Museum	6	1.89%	2012.67
7	Open Univ	6	1.89%	2013.83
8	Peking Univ	6	1.89%	2012.67
9	Univ Utrecht	6	1.89%	2012.67
10	Univ Rennes	5	1.58%	2012.80

China frequently cooperated with Germany, the USA, Italy, France, Sweden, and Canada (Figure 1.2.8); it appears at the core of the cooperative network map. There is also significant cooperation between the Chinese Academy of Sciences and other universities (Figure 1.2.9). Research in China on this topic is gradually taking the lead globally; therefore, the country should continue investing in this research area and promoting related research to accelerate the development and continue occupying the top ranks.

2 Engineering development hotspots and engineering development focus

2.1 Development trends of engineering development hotspots

The top 10 engineering development hotspots in the field of environmental engineering are summarized in Table 2.1.1. The in-depth development of traditional hotspots include: "Separation, treatment, and recovery of exhaust gas," "Wastewater treatment technology and preparation of functional materials for water treatment," "Early disaster risk warning systems," "The application of evaporators in seawater resources development," "Producing organic fertilizer by comprehensive utilization of agricultural wastes," "Radar observation and data retrieval technology," and "Satellite and aviation technology." The emerging hotspots include "Preparation of separating membrane material for environmental pollutants and membrane separation technology," "Renewable energy from biomass" and "Biomass energy from seaweed." The number of patents between 2011 and 2016 related to these individual topics are summarized in Table 2.1.2.

(1) Preparation of separating membrane materials for environmental pollutants and membrane separation technology

Please refer to Section 2.2.1.

(2) Separation, treatment, and recovery of exhaust gas

Please refer to Section 2.2.2.

(3) Wastewater treatment technologies and preparation of functional materials for water treatment

Wastewater treatment technologies purify wastewater by separating pollutants from the water or transforming them into harmless and stable substances. The key technical problems of this development topics include two aspects: ① the development of new technologies, methods, and devices for wastewater treatment; ② preparation of new functional materials for water treatment, including functional catalytic materials, high-efficiency adsorption materials, and compound coagulants. For the development of wastewater treatment technologies, current research mainly focuses on the treatment and recycling of refractory organic wastewater, the treatment and resource recovery of heavy metal-contaminated wastewater, zero discharge of industrial wastewater, desalination and recycling of wastewater, and new techniques for advanced denitrification and phosphorus removal. In the field of functional materials for water treatment, current research and development mainly focus on new catalytic

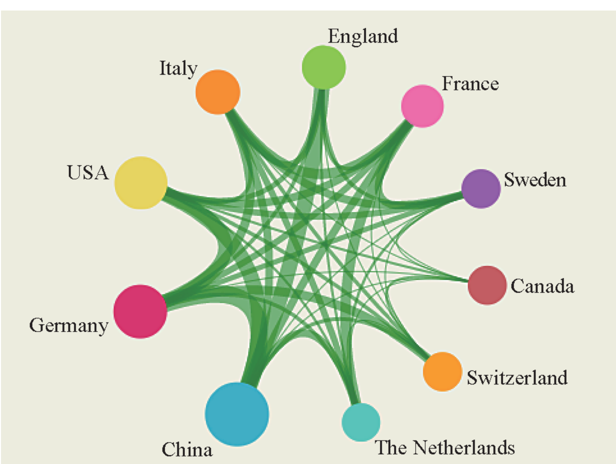


Figure 1.2.8 Collaboration network of the major producing countries or regions of core papers on the engineering research focus "Regional climate response to global change"

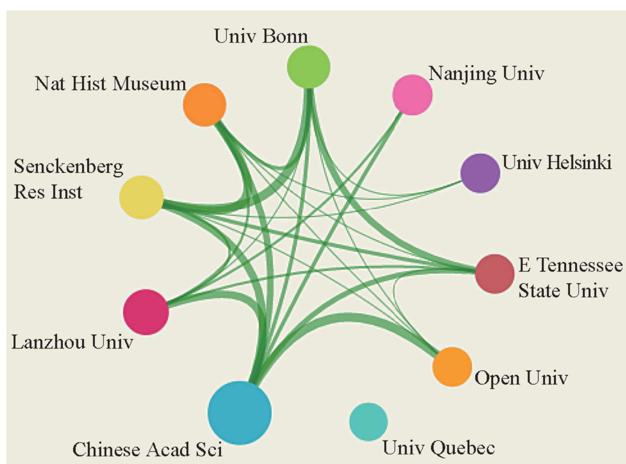


Figure 1.2.9 Collaboration network of the major producing institutions of core papers on the engineering research focus "Regional climate response to global change"

Table 2.1.1 Top 10 engineering development hotspots in environmental engineering

No.	Engineering development hotspots	Published patents	Citation frequency	Average citation frequency	Mean year
1	Preparation of separating membrane material for environmental pollutants and membrane separation technology	194	2 709	13.96	2012.16
2	Separation, treatment, and recovery of exhaust gas	827	11 571	13.99	2012.14
3	Wastewater treatment technology and preparation of functional materials for water treatment	470	7 251	15.43	2012.29
4	Renewable energy from biomass	94	2 156	22.94	2011.97
5	Early disaster risk warning systems	85	958	11.27	2012.24
6	The application of evaporator in seawater resources development	42	397	9.45	2012.15
7	Producing organic fertilizer by comprehensive utilization of agricultural wastes	216	3 340	15.46	2012.48
8	Radar observation and data retrieval technology	145	1 311	9.04	2012.33
9	Satellite and aviation technology	133	1 262	9.49	2012.29
10	Biomass energy from seaweed	64	654	10.22	2012.30

Table 2.1.2 Annual number of core patents belonging to each of the top 10 engineering development hotspots in environmental engineering

No.	Engineering development hotspots	2011	2012	2013	2014	2015	2016
1	Preparation of separating membrane material for environmental pollutants and membrane separation technology	77	54	32	18	12	1
2	Separation, treatment, and recovery of exhaust gas	360	215	112	78	44	18
3	Wastewater treatment technology and preparation of functional materials for water treatment	132	146	132	45	13	2
4	Renewable energy from biomass	36	33	18	6	1	0
5	Early disaster risk warning systems	22	33	19	10	1	0
6	The application of evaporator in seawater resources development	21	22	14	7	1	0
7	Producing organic fertilizer by comprehensive utilization of agricultural wastes	40	77	57	40	2	0
8	Radar observation and data retrieval technology	51	36	29	21	4	4
9	Satellite and aviation technology	47	38	25	13	5	5
10	Biomass energy from seaweed	20	19	12	12	1	0

materials, high-efficiency adsorption materials, membrane separation materials, and preparation of complex agents for water treatment. In recent years, research on the preparation of nano environment functional materials based on graphene and carbon nanotubes has had wide application prospects in the advanced purification of municipal sewage, treatment, and recycling of organic industrial wastewater, and recycling of heavy metal-contaminated wastewater.

In the future, the development of environmental functional materials based on nanotechnology will remain a popular research topic in the field of wastewater treatment.

(4) Renewable energy from biomass

The demand for and consumption of energy have dramatically increased since the industrial revolution. With the excessive development and use of fossil fuels, environmental problems are becoming more serious and the development of renewable energy is attracting more attention. The biomass-based renewable energy has become an important means to reduce environmental pollution and maintain the balance between energy supply and demand.

According to the United States National Energy Security Ordinance, biomass refers to renewable materials, including agricultural products and waste, timber and its waste, animal waste, urban waste, and aquatic plants. In China, biomass is usually referred to as organic matter generated from "photosynthesis," including both plants and their processed residues, crops and their residues (straw), and non-plant materials (e.g., livestock manure and sewage), and organic ingredients in wastewater and in waste.

Various straw, agricultural byproducts, recombinant microorganisms, algae, and other biomass are used for the generation of renewable energy. Renewable energy can save non-renewable resources while being conducive to environmental improvement. In the premise of protecting the environment, the transformation of traditional energy production and consumption is the only way to achieve sustained economic growth through the development of low-pollution, renewable energy technologies.

(5) Early disaster risk warning systems

Please refer to Section 2.2.3.

(6) The application of evaporators in seawater resource development

Seawater resource development mainly refers to desalination along with chemical element extraction from seawater. At present, there are two major seawater desalination technologies. The first is the membrane method, represented by reverse osmosis (RO), and the other is the distillation method, represented by multi-stage flash (MSF) and low-temperature multi-effect distillation (LT-MED). The evaporator is the key equipment for distillation technology application.

The distillation method is the earliest seawater desalination technology that was put into industrial application. The technology is characterized by high-purity producing water and suitable for use even in seriously polluted or biologically active seawater. Compared to the membrane method, distillation technology can utilize low-grade heat from power plants or other factories and offers advantages of lower raw water quality requirements and larger production capacity. Therefore, it has been one of the mainstream technologies for seawater desalination. In desalination applications, the development of high thermal conductivity and corrosion resistant materials, the technology of high-efficiency utilization of heat energy, and structural design are the main directions pertaining to progress in research on evaporators. Countries or regions such as the USA, Israel, Japan, Singapore, Korea, Spain, Germany, France, and the UK are leaders in this technical field and the main exporting countries or regions for technologies and products regarding seawater desalination. The Middle East is the largest producer of desalinated water in the world.

Seawater desalination increases the availability of freshwater resources at the expense of energy consumption. To achieve the high-efficiency utilization of seawater resources, the primary problem that must be solved is to reduce the energy consumption and cost of desalination.

(7) Producing organic fertilizer by comprehensive utilization of agricultural wastes

Solid waste is the main material used to produce bio-organic fertilizer via aerobic composting technology. This technology is characterized by thorough decomposition and fewer odors. Composting technology uses microorganisms to decompose organic matter in waste into organic-rich soil that contains nitrogen, phosphorus, potassium, and other nutrients in clinker. Depending on the requirements pertaining to the natural soil ecological structure and nutritional elements, trace elements, beneficial microorganisms, nitrogen, potassium, phosphorus for the growth and other activities of crops are converted into liquid products. The solid agent produced by the compost can be combined with the bacterial fluid produced by the cultured microorganisms to produce a biological fertilizer with widespread effect. The development of bio-organic fertilizer not only provides crops with nutrition, but also increases agricultural production and income, protects soil fertility and the rural environment, and maintains the circular economy. Irrespective of the purpose (developing green agricultural products, under taking sustainable agriculture, ensuring pollution-free production, reducing pesticide and fertilizer use, producing less environmental pollution, lowering production costs, promoting biotechnology, or producing bio-organic fertilizer), these applications have good future prospects.

(8) Radar observation and data retrieval technology

This research focus belongs to the field of meteorology, which is a traditional research field. The meteorological radar can detect the three-dimensional structure and evolution trend of the precipitation system and obtain the three-dimensional structure of precipitation with the highest spatial and temporal resolution. The key technologies of radar observation and data retrieval include the development of new detection technologies, such as dual polarization radar, phased array weather radar, and multiband vertical observation radar; the inversion method for microphysical and dynamical parameters of cloud precipitation; and the radar data assimilation method. Dual-polarization radar is one of the key technologies adopted by the next generation radar in China. Radar-phased arrays shared by meteorological, aviation, and military industries comprise a more advanced radar system.

(9) Satellite and aviation technology

Satellite observation is an important component of a comprehensive observation network of meteorological science. However, significant scope for improvement remains: internationally, China lags behind with regard to research on key technical problems associated with meteorological satellites, such as quantitative aspects, product quality, and application capability. Therefore, mastering the core processing and data inversion technologies of meteorological satellites are core topics for future research. At the same time, key technologies of meteorological satellites and their applications should be developed in a planned, hierarchical, and phased way, so that they can play an important role in monitoring floods, earthquakes, forest fires, and other disaster events.

(10) Biomass energy from seaweed

Seaweed, with its high photosynthetic efficiency, is an ideal biomass resource. Compared to terrestrial plants, it facilitates higher yields of biomass production. The report from the Global Oil Club shows that 1 ha of seaweed can generate 96 000 L of biodiesel per year, which is much higher than the amount generated by coconuts (5950 L) and soybeans (446 L).

The production of biodiesel from seaweed contains four main steps including large-scale seaweed cultivation, seaweed oil extraction, lipid exchange reaction, and biodiesel post-treatment. The most critical step concerns large-scale seaweed cultivation. Other countries have made headwayin using seaweed to prepare biofuel. Many large international petrochemical companies such as Exxon, DuPont, and Dow Chemical are very optimistic about the biofuel technology and have been actively researching and developing new techniques. To date, they have successfully produced fuel using CO_2 and seaweed. Using seaweed to produce ethanol and biodiesel has become the new favorite topic in the energy sector in many countries. The development of biofuel technology in China keeps pace with global advances and is mainly contributed by domestic institutes with strong research programs, such as the Institute of Oceanology CAS and Ocean University of China. The Chinese Academy of Sciences has been instrumental in creating a key technology for biodiesel production.

Overall, the current technology is still in the early stages of development and is highly affected by the international energy market. The main problems are the high cost of industrial applications and poor industrial design. Large-scale industrial production remains to be achieved.

2.2 Understanding of engineering development focus

2.2.1 Preparation of separating membrane material for pollutants and membrane separation technology

Membrane technology has been applied to water treatment since the 1960s and has become one of the technologies with great potential for developments in water treatment. Membranes are used in various processes such as microfiltration, ultrafiltration, and nanofiltration. Reverse osmosis membranes intercept and hold onto pollutants of various sizes such as colloid particulates, organics, heavy metal ions, and saline ions. Membrane separation is a physical separation process free of chemical agents and secondary pollution; thus, it can compete with other water quality purification processes on the premise of non-interference or less interference with water. Therefore, it is considered a "green" water treatment technology. In addition, water treatment technologies based on membrane separation are characterized by their compact unit structure, and may or may not include simple pretreatment systems to directly carry out membrane separation using limited resources and land. With the constant and rapid improvement in membrane materials, continuous optimization of membrane modules, and gradual perfection of technology, the membrane separation technology decreases specific energy consumption and lowers investment and operation costs. Membrane separation technology has already become a mainstream technology with the greatest promise for water and wastewater treatment.

The type of membrane material lies at the core of this technology. Membrane materials are made from organic polymer and ceramics, carbon nanometer materials such as grapheme, and metal oxide nanometer materials such as titanium dioxide. The utilization of the modified membranes is the main focus of future development. New materials are developed to improve membrane flux, reduce membrane pollution, prolong the service life of membrane materials, and enhance their efficiency to intercept and remove pollutants.

Of the 194 patents relevant to membrane separation granted in the last 5 years, patents on membrane materials account for 60% of total patents. Five of the most cited patents originate from the USA, indicating that this country is the world leader in investment and research and development in membrane technology. Regarding the core patents listed in Table 2.2.1, the USA ranks first with regard to the number of patents related to membrane separation, with 41.24% of the total patents, and total and average citation frequencies of 1,167 and 14.59, respectively.

China produced 51 patents, ranking second in the field, with an average citation frequency of 12.88, indicating that

Table 2.2.1 Major producing countries or regions of core patents on the engineering development focus "Preparation of separating membrane material for environmental pollutant and membrane separation technology"

No.	Country/Region	Published patents	Proportion of published patents	Citation frequency	Proportion of citation frequency	Average citation frequency
1	USA	80	41.24%	1167	43.08%	14.59
2	China	51	26.29%	657	24.25%	12.88
3	Japan	30	15.46%	465	17.17%	15.50
4	Korea	10	5.15%	124	4.58%	12.40
5	UK	9	4.64%	126	4.65%	14.00
6	German	8	4.12%	76	2.81%	9.50
7	The Netherlands	6	3.09%	91	3.36%	15.17
8	Singapore	4	2.06%	73	2.69%	18.25
9	Austria	2	1.03%	36	1.33%	18.00
10	Australia	2	1.03%	14	0.52%	7.00

Table 2.2.2 Major producing institutions of core patents on the engineering development focus "Preparation of separating membrane material for environmental pollutant and membrane separation technology"

No.	Institution	Published patents	Proportion of published patents	Citation frequency	Proportion of citation frequency	Average citation frequency
1	TORA	16	8.25%	206	7.60%	12.88
2	DOWC	12	6.19%	169	6.24%	14.08
3	FUJF	11	5.67%	189	6.98%	17.18
4	GENE	7	3.61%	57	2.10%	8.14
5	Oasys Water	5	2.58%	61	2.25%	12.20
6	SIEI	5	2.58%	98	3.62%	19.60
7	SMSU	4	2.06%	86	3.17%	21.50
8	Celgard LLC	3	1.55%	65	2.40%	21.67
9	EVON	3	1.55%	41	1.51%	13.67
10	IBMC	3	1.55%	65	2.40%	21.67

Note: TORA stands for Toray Industries Inc.; DOWC stands for Dow Global Technologies Inc.; FUJF stands for Fuji Film Co., Ltd.; GENE stands for General Electric Co.; SIEI stands for Siemens Water Technologies Corp.; SMSU stands for Samsung Electronics Co., Ltd.; EVON stands for Evonik Fibers Gmbh; IBMC stands for Machines Corp.

it holds an influential global position in patent technology. Table 2.2.1 shows that Japan, Korea, the UK, Germany, Singapore, Austria, and Australia follow the USA and China.

Table 2.2.2 shows the major organizations that produce the core patents in the world for this technology. Five of them are located in the USA, two are in Japan and Germany, and one is in Korea. Toray Industries, Inc., Dow Chemicals, FUJI, and General are leading organizations for research, development, and production of membrane materials in the world; in particular, they benefit from a larger market share in the high-end reverse osmosis membrane field. China has no enterprises in the top ten list related to this focus, indicating that research and development in this field are yet to be established and improved.

In the field of membrane materials, ultra-filtration and micro-filtration are relatively simple technologies to develop, and thus the market is not monopolized. Membrane materials, membrane production mechanisms, and membrane modules, together with system integration and application technology, are undergoing many developments with each passing day, and the technological monopoly in this area is missing. China has more than 200 ultra-filtration and micro-filtration membrane manufacturers, with new manufacturers emerging in large numbers every day.

In contrast, a higher level of technology is needed for reverse osmosis membranes; thus, the market is still monopolized by large membrane producing corporations in the USA and Japan. Homemade ultra-filtration membranes are undergoing rapid growth. They have been successfully applied to many large-scale projects and have started to dominate the market in terms of quantity. Beijing Origin water Technology Co., Ltd and Tianjin Motimo Membrane Technology Co., Ltd. have been listed on the Growth Enterprise Market as leading membrane manufacturers in China. It is imperative for China to address technological problems in reverse osmosis membranes, to be able to market them as high-end membrane materials and play an influential role globally.

Figure 2.2.1 shows that there is a cooperative relationship among the leading countries or regions. The UK has close relations with the Netherlands and China; the USA works with Singapore and Australia for research and development on patent technology. There is no cooperation among the primary enterprises on patent technology (Figure 2.2.2).

2.2.2 Separation, treatment, and recovery of exhaust gas

In recent years, the problem of air pollution in China has attracted worldwide attention due to the frequent occurrences of fog and haze. Industrial emissions and automobile exhaust are now recognized as major sources of air pollution. Exhaust gas separation, treatment, and recovery have been studied for a long time in Europe, the USA, and other developed countries. China is gradually paying attention to relevant work in this area. At present, the development in this field is divided into two parts: industrial waste gas separation treatment and engine exhaust treatment. Industrial waste gas treatment focuses on

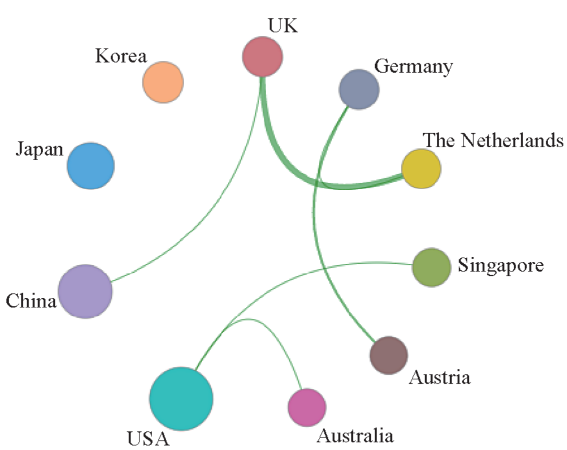


Figure 2.2.1 Collaboration network of the major producing countries or regions of core patents on the engineering development focus “Preparation of separating membrane material for environmental pollutant and membrane separation technology”

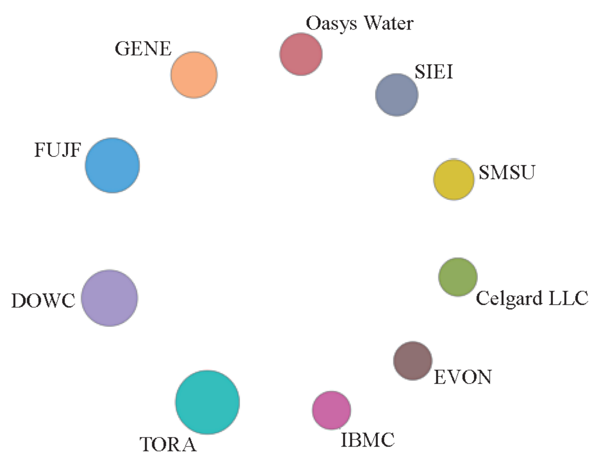


Figure 2.2.2 Collaboration network of the major producing institutions of core patents on the engineering development focus “Preparation of separating membrane material for environmental pollutant and membrane separation technology”

the removal of industrial nitrogen oxides (NO_x), volatile organic compounds (VOCs), and heavy metals (Hg and Pb)in industrial furnaces (steel, cement, glass, and waste incineration furnaces); coupled selective non-catalytic reduction (SNCR) and low-temperature selective catalytic reduction (SCR) technology; multi-pollutant control parameters and pollution purification efficiency; zero emissions power generation; combined removal of flue gas pollutants (SO_2/NO_x/composite particles/VOCs) via wet electrostatic purification; efficient removal of multiple pollutants ($PM_{2.5}$ and SO_3, mercury, and other acidic gases); SCR base spray; co-removal of mercury, the optimization design of flue gas chimney, research and development regarding high-temperature gas filtration materials; high-efficiency purification technology of flue gas denitrification and mercury removal; and key technologies of new SCR denitrification. With regard to engine exhaust gas treatment technology, developed countries focus on the application of the DOC (diesel oxidation catalyst) + DPF (diesel particulate trap) + SCR combination purification technology on diesel engines, as well as the quantity and quality of pollutant emissions. For diesel vehicles, the engine exhaust gas treatment technology also focuses on the development of a wide temperature window, high heat resistant SCR catalyst, high thermal stability and low thermal expansion DPF material; on optimization of device and engine matching and integrated post-processing. Break through technical problems concern high efficiency, combination, purification, and matching control. For gasoline vehicles, key research focuses on automobile exhaust purification, creation of three-way catalyst using low noble metal content and providing long service life; developing new close-coupled catalytic converters to solve the issue of emissions discharged during the cold start phase; studies on gasoline vehicle purification technology under lean burn conditions, and combining the fourth generation automobile fault diagnosis system with remote diagnosis and vehicle networking.

Core patents on exhaust gas separation, processing, and recycling are mostly from the USA (425 patents; Table 2.2.3). The top 10 list of core patent institutions includes eight American institutions. Japan and Germany rank second and third with 159 and 85 patents, respectively. China ranks fourth with 58 patents followed by the UK, Korea, Switzerland, France, Canada, and Sweden. The top 10 countries or regions are mainly located in Europe and America given their pace of local industrial development, especially that pertaining to the automobile industry.

The total and average citation frequencies of the patents from the USA are 6740 and 15.86 respectively, much higher than those of the other countries or regions (Table 2.2.3). The gaps between China (58 patents) and the USA and Japan are still quite large, showing the lack of originality and influence of China's patented technology in this area.

The top 10 institutions (Table 2.2.4) with the highest number of patents include some large car and petrochemical, and clean diesel technology companies. Chinese institutions do not appear in the top 10 list, indicating the

Table 2.2.3 Major producing countries or regions of core patents on the engineering development focus "Separation, treatment and recovery of exhaust gas"

No.	Country/Region	Published patents	Proportion of published patents	Citation frequency	Proportion of citation frequency	Average citation frequency
1	USA	425	51.39%	6740	58.25%	15.86
2	Japan	159	19.23%	1908	16.49%	12.00
3	Germany	85	10.28%	1016	8.78%	11.95
4	China	58	7.01%	793	6.85%	13.67
5	UK	36	4.35%	329	2.84%	9.14
6	Korea	33	3.99%	502	4.34%	15.21
7	Switzerland	14	1.69%	166	1.43%	11.86
8	France	11	1.33%	119	1.03%	10.82
9	Canada	9	1.09%	104	0.90%	11.56
10	Sweden	9	1.09%	71	0.61%	7.89

Table 2.2.4 Major producing institutions of core patents on the engineering development focus "Separation, treatment and recovery of exhaust gas"

No.	Institution	Published patents	Proportion of published patents	Citation frequency	Proportion of citation frequency	Average citation frequency
1	FORD	70	8.46%	967	8.36%	13.81
2	CLEA	39	4.72%	410	3.54%	10.51
3	GENE	31	3.75%	465	4.02%	15.00
4	GENK	30	3.63%	296	2.56%	9.87
5	BADI	29	3.51%	435	3.76%	15.00
6	JOHO	29	3.51%	274	2.37%	9.45
7	TOYT	23	2.78%	373	3.22%	16.22
8	CUND	20	2.42%	387	3.34%	19.35
9	KOMS	20	2.42%	201	1.74%	10.05
10	CATE	15	1.81%	312	2.70%	20.80

Note: FORD stands for Ford Global Tech LLC; CLEA stands for Clean Diesel Technologies Inc.; GENE stands for General Electric Co.; GENK stands for GM Global Technology Operations Inc.; BADI stands for BASF Corp.; JOHO stands for Johnson Matthey PLC; TOYT stands for Toyota Motor Corp.; CUND stands for Cummins IP Inc.; KOMS stands for Komatsu Seisakusho KK; CATE stands for Caterpillar Inc.

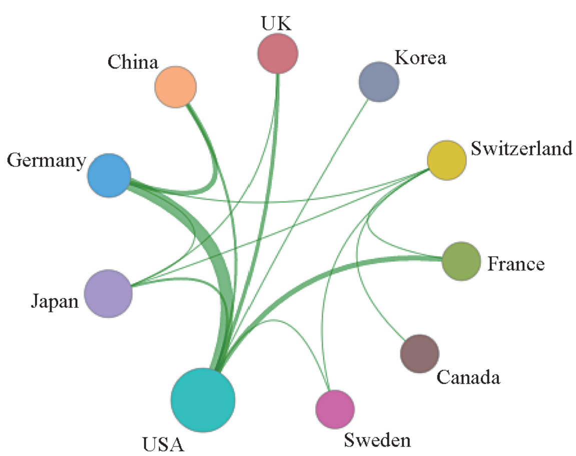


Figure 2.2.3 Collaboration network of the major producing countries or regions of core patents on the engineering development focus "Separation, treatment and recovery of exhaust gas"

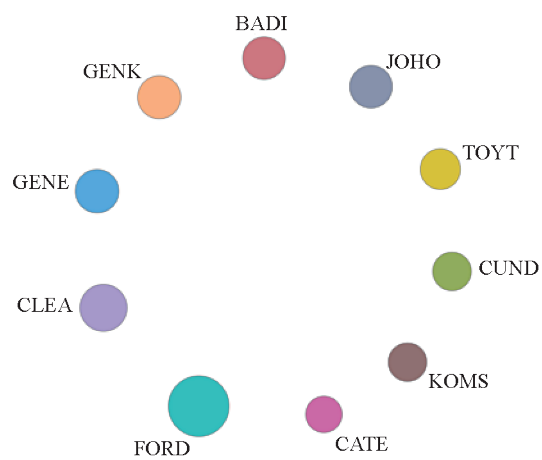


Figure 2.2.4 Collaboration network of the major producing institutions of core patents on the engineering development focus "Separation, treatment and recovery of exhaust gas"

scattered distribution of institutions in China.

Out of 15 patents related to the automobile exhaust treatment, 7 belong to universities (including 2 from Shanghai Jiao Tong University), 3 to individuals, and 5 to enterprises. The dominance of the companies in the list of the top 10 core institutions suggests the need for further industrialization in this area in China.

Figure 2.2.3 shows the close relationships between the USA and Germany, which also have cooperative tie-ups with China. The USA, the UK, France, and Korea are leaders in patent technology research and development in this field. Figure 2.2.4 shows that there is no research and development cooperation between individual enterprises.

2.2.3 Early disaster risk warning systems

This research focus is related to meteorology. Early warning mainly emphasizes repairs and restoration after disasters and does not concern disaster prevention and preparedness. Since the losses and damages caused by disasters in the world are becoming increasingly serious, early warning of disaster risks has become an important aspect of disaster risk mitigation. At this stage, early warning systems and monitoring networks for floods, droughts, and other disasters are established using multi-source observation data to monitor disasters automatically. However, the current network is far from meeting the requirements. Therefore, conducting research on satellite remote sensing, radar data processing, and early warning systems with excellent visualization and high security is key to reducing the damage from disasters.

Among the main output countries of cited papers, China ranks first (72), followed by the USA (9) and Germany (2). With regard to total citations, China still ranks first (790), followed by the USA (160) and Germany (3) (Table 2.2.5).

The output institutions for the core patents in the top three spots are SGCC (6), ROCW (3), and Chinese Academy of Sciences Chengdu Institute (2). The top three institutions with the largest average citations are UNBA (17.50), Chinese Academy of Sciences Chengdu Institute (14.00), and SGCC (13.67) (Table 2.2.6).

China ranked first for the number of core patents and it is gradually taking the global lead. Therefore, the country should increase investment in this research field and promote related research fields to accelerate development efforts in this area.

There is no cooperation among the leading countries (Figure 2.2.5) or the institutions, except for that between the China National Grid and Beijing University of Aeronautics and Astronautics (Figure 2.2.6).

Table 2.2.5 Major producing countries or regions of core patents on the engineering development focus "Early disaster risk warning systems"

No.	Country/Region	Published patents	Proportion of published patents	Citation frequency	Proportion of citation frequency	Average citation frequency
1	China	72	84.71%	790	82.46%	10.97
2	USA	9	10.59%	160	16.70%	17.78
3	Germany	2	2.35%	3	0.31%	1.50
4	France	1	1.18%	2	0.21%	2.00
5	Korea	1	1.18%	3	0.31%	3.00

Table 2.2.6 Major producing institutions of core patents on the engineering development focus "Early disaster risk warning systems"

No.	Institution	Published patents	Proportion of published patents	Citation frequency	Proportion of citation frequency	Average citation frequency
1	SGCC	6	7.06%	82	8.56%	13.67
2	ROCW	3	3.53%	29	3.03%	9.67
3	Chinese Acad Sci Chengdu Inst	2	2.35%	28	2.92%	14.00
4	CRCC	2	2.35%	12	1.25%	6.00
5	First Inst Surveying & Mapping Province	2	2.35%	26	2.71%	13.00
6	IWHR	2	2.35%	19	1.98%	9.50
7	Shanghai CEE TEK Co., Ltd.	2	2.35%	20	2.09%	10.00
8	UCHA	2	2.35%	20	2.09%	10.00
9	UNBA	2	2.35%	35	3.65%	17.50
10	Univ Qingdao Technological	2	2.35%	20	2.09%	10.00

Note: SGCC stands for State Grid Corporation of China; ROCW stands for Rockwell Collins Inc.; CRCC stands for China Railway Construction Corporation Limited; IWHR stands for China Institute of Water Resources and Hydropower Research; UCHA stands for Chang'an University, China; UNBA stands for Beijing University of Aeronautics and Astronautics.

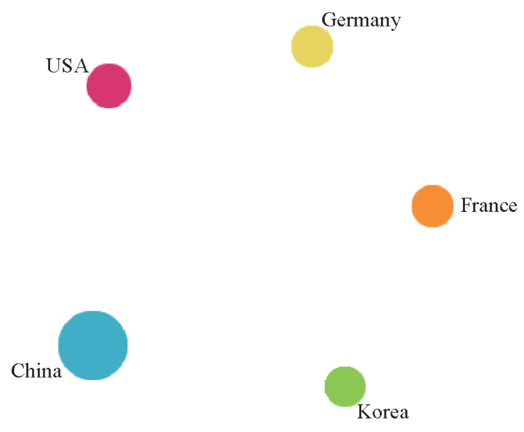


Figure 2.2.5 Collaboration network of the major producing countries or regions of core patents on the engineering development focus “Early disaster risk warning systems”

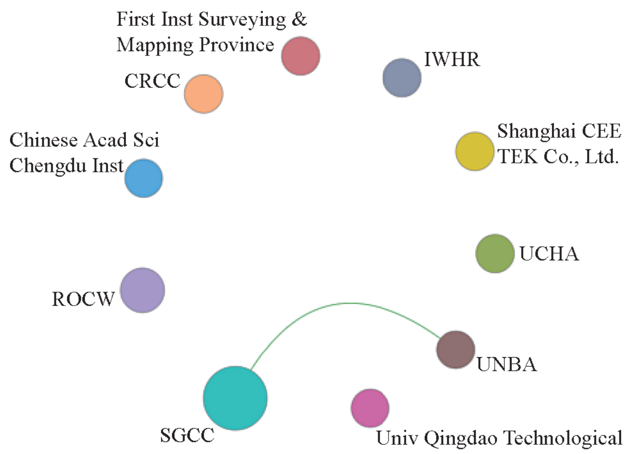


Figure 2.2.6 Collaboration network of the major producing institutions of core patents on the engineering development focus “Early disaster risk warning systems”

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