VI. Environmental and Light Textile Engineering

1 Engineering research fronts

1.1 Trends in top 10 engineering research fronts

The top 10 engineering research fronts in the field of environmental and light textile engineering (hereafter referred to as environmental engineering) include the subfields of environmental science engineering, meteorological science engineering, marine science engineering, food science engineering, textile science engineering, and light industry science engineering. The citation statistics for these research fronts and the annual number of core papers for each research front between 2014 and 2019 are summarized in Tables 1.1.1 and 1.1.2, respectively.

(1) Microinterfacial behavior and co-selection of antibiotic resistance genes in the environment

Environmental pollution caused by antibiotic resistance genes poses a direct threat to human health. However, the lack of large-scale quantitative studies on antibiotic resistance genes in most types of environments, and on humans and animal subjects, as well as the lack of data on resistance genes of potential co-selection reagents (such as fungicides and metals) have hindered the effective identification of environmental risks. It is therefore necessary to carry out detailed research on antibiotic resistance genes to reduce their potential environmental impacts. Among them, the migration, transformation, and fate of antibiotic resistance genes on environmental surfaces (microinterface behavior) and the interaction between antibiotic resistance genes and other resistance genes (co-selection mechanism) are the most important processes. Based on the existing literature, it is evident that natural system and human activities have a significant impact on the distribution of antibiotic resistance genes in the environment. Heavy metal resistance genes play an important role in the transmission of some antibiotic resistance genes; sewage treatment plants are one of the main sources of antibiotic resistance genes in the environment. Therefore, further studies on the effects and behavior patterns of these genes are required to guide risk-reduction actions.

(2) Microinterface behavior of combined pollution process

Consumption of coal, oil, and other energy resources, as well as continuous growth of industrial agglomeration and

Table 1.1.1 Top 10 engineering research fronts in environmental and light textile engineering

No.	Engineering research front	Core papers	Citations	Citations per paper	Mean year
1	Microinterfacial behavior and co-selection of antibiotic resistance genes in the environment	15	1 478	98.53	2015.7
2	Microinterface behavior of combined pollution process	57	3 400	59.65	2015.9
3	Catalytic performance of nanocomposites and their mechanism of action in wastewater treatment	66	3 083	46.71	2017.9
4	Pollution and toxicology of microplastics in environmental water	83	14 173	170.76	2015.9
5	Urban heat-island effect and urban planning	55	3 772	68.58	2015.8
6	Meteorology and sustainable development	26	1 172	45.08	2016.1
7	New spatial pattern and controlling factors of marine biological nitrogen fixation	26	1 326	51.00	2015.2
8	Precise dietary regulation technology based on intestinal flora intervention	80	12 040	150.50	2015.0
9	Degradation potential of dye-based industrial pollutants	274	20 097	73.35	2016.4
10	Ultra-low emission technology for pollution caused due to pulping and papermaking	2	105	52.50	2015.5

Table 1.1.2 Annual number of core papers published for the top 10 engineering research fronts in environmental and light textile engineering

No.	Engineering research front	2014	2015	2016	2017	2018	2019
1	Microinterfacial behavior and co-selection of antibiotic resistance genes in the environment	3	2	8	1	1	0
2	Microinterface behavior of combined pollution process	16	10	10	10	8	3
3	Catalytic performance of nanocomposites and their mechanism of action in wastewater treatment	0	2	8	11	18	27
4	Pollution and toxicology of microplastics in environmental water	15	19	19	18	11	1
5	Urban heat-island effect and urban planning	12	9	15	14	5	0
6	Meteorology and sustainable development	6	4	7	2	5	2
7	New spatial pattern and controlling factors of marine biological nitrogen fixation	13	5	2	4	1	1
8	Precise dietary regulation technology based on intestinal flora intervention	20	14	13	8	6	2
9	Degradation potential of dye-based industrial pollutants	0	71	88	63	38	14
10	Ultra-low emission technology for pulping and papermaking pollution	0	1	1	0	0	0

extensive application of fertilizers and pesticides, has resulted in the release of several pollutants into the environment. This, in turn, has threatened the safety of agricultural products and the health of people. Pollutants in the environment do not occur singly; they exist in multiple forms and in various media simultaneously.

After entering the environment, pollutants undergo a series of physical/chemical/biological interfacial processes, such as adsorption/desorption, volatilization, reduction/oxidation, chemical precipitation/complexation/degradation, biological transformation/degradation and/or adsorption/transport via biological membranes. Because the environment is highly heterogeneous, pollutants always show interfacial and coupling effects, which make it difficult to predict their distribution, migration, and biological/ecological effects by using a single linear model. Thus, there is an urgent need to study the microinterface behavior of the composite fouling process, revealing the medium and coupling interface behavior mechanism, clarifying the environment pollutant migration process, and reducing their biological effects.

(3) Catalytic performance of nanocomposites and their mechanism of action in wastewater treatment

With the development of the social economy, water pollution has become increasingly serious. Based on environmental and health considerations, the top priority is to develop efficient wastewater treatment technologies, such as the use of nanomaterials. The high specific surface area of nanomaterials can expose more active sites, provide more reaction sites, and exhibit excellent performance in mechanical, thermal, optical, and electrical fields. Nanocomposites combine the advantages of a variety of nanomaterials. Through the design of raw materials, distribution of each component, and process conditions, the advantages of each component can be complemented and maximized, and therefore, the components can be utilized in a synergistic manner improving the overall catalytic performance. Research on the catalytic mechanism of nanocomposites is currently focused on the following aspects: 1) preparation of a composite material with strongly oxidizing free radicals and enhanced redox activity; 2) microstructure and performance of composite materials; 3) interface mechanism between various nanomaterials. Nanocomposites are widely used in the field of environmental restoration and for storing solar energy; their applications include: photocatalytic treatment of persistent organic pollutants, oxidation/reduction of heavy metal-ions, oxidative decomposition of pathogens, splitting of water for H_2 evolution, and CO_2 reduction. With the further development of technology, nanocomposite materials will also be used in emerging applications such the development of solar cells and biosensors. Therefore, in the future, joint efforts are required to develop more suitable nanocomposite materials so that they can be applied for the production of clean energy on a large scale, and ultimately achieve true sustainable development and the protection of the environment.

(4) Pollution and toxicology of microplastics in environmental water

Microplastics are plastic particles with a particle size of less than 5 mm. They are organic pollutants originating from various plastic products and easily migrate in the environment. Microplastics are highly toxic. Further, they can also adsorb other pollutants in enviornmental water, which enhances their toxic potential. Because of their small particle size, they are also easily ingested by zooplankton or passed along the food chain, accumulated and transferred in organisms, and produce irreversible toxic effects.

Microplastics have become a new type of pollutant worldwide, and the resulting environmental problems are becoming increasingly serious. The world’s plastic production, consumption, and application areas are rapidly expanding. Due to the physical and chemical properties, plastics release toxic additives to water bodies, absorb hydrophobic organics, increase water toxicity, and pass through the food chain through biological predation. Therefore, the pollutants accumulated on the surface of microplastics can also be transmitted through the food chain and continuously enriched and amplified at different trophic levels, ultimately causing harm to human health. It is necessary to study the pollution and toxicology of microplastics in environmental water and identify solutions for microplastic treatment.

(5) Urban heat-island effect and urban planning

The urban heat-island (UHI) effect refers to the change in the thermal properties of the urban underlying surface (the contact surface between the bottom of the atmosphere and the ground), which is characterized by high temperatures in urban areas and relatively low temperatures in the suburbs. On the meteorological near-surface atmospheric isotherm map, the wide areas in the suburbs show little temperature change, analogous to a calm sea, while urban areas are high-temperature areas, like an island protruding from the sea. Because this type of island represents a high-temperature urban area, it is called an urban heat island.

The formation of UHIs is inseparable from urbanization. Microclimate changes caused by human activities are most significant in winter and during the night compared to the daytime; these are the most obvious characteristic of an urban climate. Many buildings and roads in urban areas constitute the underlying layers of cement, asphalt, and other materials. The thermal capacity and conductivity of these materials are much larger than those used in suburban areas; meanwhile, their reflectance to sunlight is low and the absorption rate is high. Therefore, during daytime, the surface temperature of the urban under layer is much higher than that of the suburbs. The heat-island effect results in the annual mean temperature in the city being higher than that in the suburbs by at least 1 °C. In summer, the temperature in some parts of the city is sometimes 6 °C higher than that in the suburbs. In addition, the dense and tall buildings block the air flow, reducing wind speed and increasing air pollution in the city.

The research front mainly focuses on the impact of the UHI effect, which should be fully considered in urban planning and design. Therefore, as urban development intensifies the heat-island effect, it is necessary to control the population and building density. In addition, management of urban water system must be considered to adjust to the changes in urban climate; effective urban water system management can achieve the purpose of decelerating the UHI.

Furthermore, to strengthen urban ventilation and reduce heat intensity in urban heat islands, it is necessary to widen the streets in the north-to-south direction when expanding or reconstructing new or old urban areas, respectively. In summary, it is very important to properly use the existing technology, control the rapid development of cities through reasonable planning, and fully consider and use meteorological factors in the development.

(6) Meteorology and sustainable development

Sustainable development is the kind of development that can meet the needs of the present without threatening the ability of future generations to meet their own needs. Its core is economic prosperity, social equity, and ecological security for generations. Meteorology has a unique position in achieving comprehensive, coordinated, and sustainable development. It involves the rational development and utilization of meteorological resources and plays an irreplaceable role in the protection of other natural resources and the ecological environment.

The concept of “meteorological resources” includes developing applicable technologies to strengthen research in the field of meteorology, and determines the optimal and limit value (or carrying capacity) of meteorological elements, such as wind, solar radiation, precipitation, among other meteorological resources.

At present, conventional energy sources are facing depletion. Meanwhile, environmental pollution and ecological deterioration, caused by energy production, are seriously impacting the living environment, prompting all countries to urgently consider optimal energy planning for sustainable development.

China has conducted various works in the fields of meteorology and sustainable development; increased attention has been paid to the technical research on, and development and usage of, renewable energy. Scientific and technological research in these fields of renewable energy has been identified as a priority area for scientific and technological development. It has been emphasized that attention should be paid to the optimization and adjustment of climate resources in sustainable development; these include research on the distribution, quantity, and quality of climate resources in a way that is beneficial to human utilization.

(7)New spatial pattern and controlling factors of marine biological nitrogen fixation

Marine biological nitrogen fixation refers to the transformation of atmospheric nitrogen into available biological ammonium. Marine biological nitrogen fixation can provide “new” sources of nitrogen that drive the assimilation and sequestration of marine carbon. It is critical for maintaining the ocean’s primary productivity and the budget of carbon and nitrogen cycling.

Current research topics include the spatial and temporal distribution patterns, regulation mechanisms, and activity of nitrogen-fixing microorganisms in the global ocean and coastal waters. In the context of global environmental change (e.g., ocean warming, acidification) and the impact of human activities (e.g., atmospheric nitrogen deposition, land runoff), further exploration will improve our understanding of marine biological nitrogen fixation trends and their impact on ocean productivity and biogeochemistry.

Other topics pertaining to marine biological nitrogen fixation that merit investigation include geographical distribution patterns, nitrogen contribution to the coastal zone, and primary productivity and sustainability in typical offshore ecosystems such as mangroves, seagrass beds, and coral reefs. Furthermore, in deep-sea ecosystems, especially in cold seep and hydrothermal areas, research on the coupling of chemoautotrophs and biological nitrogen fixation should be research hotspots. Genomics, isotope tracing, and deep learning will play an important role and will be critical to the research field of marine biological nitrogen fixation in the future. Lastly, the development and application of ecological nitrogen-fixing bacterial agents for marine ecological engineering is also a significant research field.

(8) Precise dietary regulation technology based on intestinal flora intervention

Intestinal flora is the general term for microorganisms inhabiting the intestinal system, and it is closely related to human health and diseases. Healthy intestinal flora can protect the human body from pathogenic bacteria and participate in many physiological processes, including biological activity metabolism, immune regulation, and glucose and lipid metabolism. As the main nutrients in the diet, fats, proteins, and carbohydrates provide energy to the human body and have an important impact on the composition of the intestinal flora. An unreasonable dietary structure will result in an imbalance the intestinal flora, which is significantly related to the occurrence and development of obesity, depression, diabetes, and related metabolic diseases. At the same time, differences in individual genes, living habits, and living environment can also affect the intestinal flora; therefore, based on these conditions, it is important to set personalized dietary recommendations. A regulated regime aims to combine scientific dietary guidelines to provide personalized recommendations based on the nutritional needs of individuals and their intestinal flora to achieve disease prevention and control. Therefore, precise dietary regulation based on the intervention of intestinal flora is of great significance to improve human health.

(9)Degradation potential of dye-based industrial pollutants

The wanton discharge of dye-based industrial pollutants not only leads to excessive waste of resources, but also causes serious water pollution and environmental degradation threatening the living environment and health of humans. It is of great practical significance and application value to develop efficient and low-cost degradation and reuse technologies for dye-based industrial pollutants. Textile printing and dyeing wastewater contain a variety of harmful substances, such as reactive dyes. Dyes can absorb light, reduce the transparency of water, affect the growth of aquatic organisms and microorganisms, and are not conducive to water self-purification. Phthalein bronze and some azo dyes are highly toxic and can directly or indirectly threaten human health when they enter the biological food chain. Therefore, dye-based industrial pollution is an urgent global problem that needs to be addressed. Dye-based industrial pollutants mainly exist in the form of water mixtures. Due to the diversity of textile dyes and water pollutants, the main degradation and treatment methods, such as physical adsorption, chemical oxidation, and aerobic biological treatment, are generally inefficient and costly, as wastewater is difficult to reuse. At present, many countries are focusing on the degradation and reuse of dye-based industrial pollutants. The main research directions in this field focus on the design and preparation of fiber-based high-efficiency and low-cost dye-based pollutant degradation membranes, synthesis of novel materials, screening of microorganisms, and construction and engineering of physical–chemical–biological combined degradation systems.

(10) Ultra-low emission technology for pollution caused due to pulping and papermaking

Vast quantities of wastewater are inevitably generated during pulping and papermaking, which has made the protection of the ecological environment highly challenging. Recently, due to the shortage of water resources, environmental pressures have become more severe; thus, more stringent national and local standards have been issued, which have put forth stricter environmental protection requirements for the pulping and papermaking industries. In this case, ultra-low emission technology has become an important research direction for achieving clean and green pulping and papermaking.

Conventional technologies usually fail to achieve the standards of wastewater discharge, while the ultra-low emission of pollution from pulping and papermaking is a promising deep treatment approach to achieve this objective. At present, various technologies have been applied for attaining ultra-low emissions of pulping and papermaking pollution, including membrane separation in bioreactors, activated carbon adsorption, advanced oxidation, sand filtration, magnetic finishing, magnetization–enzyme-like catalytic condensation, oxidation ponds, and constructed wetlands. However, the existing ultra-low emission technologies still suffer from many disadvantages, such as high costs, difficulty in maintenance, low mass transfer efficiency, difficult regeneration, and operation instability. Therefore, future investigations will focus on deep treatment technologies that are highly efficient, cost-effective, and stable, with the aim of achieving clean and green production pulping and papermaking.

1.2 Interpretations for three key engineering research fronts

1.2.1 Microinterface behavior of combined pollution process

The types of pollutants present in the environment and their interaction with each other affects their migration, transformation, and bioavailability. Because the effects of a compound are complex, it is impossible to accurately predict its environmental risks and regulate its concentrations. Hence, pollution remediation is difficult, costly, and ineffective, threatening the safety of agricultural products and human health. Past research focused on the compound effects of pollutants in terms of their toxicity, especially that resulting due to synergism or antagonism between heavy metals, and combined pollution caused by them in soil–water–gas–biological/microorganism systems and microinterface. However, the precise behavior of pollutants remains unclear, making it difficult to accurately predict the physical, chemical, and biological processes these pollutants are involved in and the associated environmental risks. Therefore, exploration of the microinterface behavior of combined pollution is urgently required to provide theoretical support for bioavailability regulation, pollution control, and remediation.

In recent years, studies on the microinterface behavior of combined pollution processes have been conducted resulting in a series of innovative works on the characteristics, migration, transformation, in situ characterization technology, and bioavailability of pollutants on the water–soil–gas–biological microinterface. As shown in Table 1.2.1, among the 57 core papers in the past five years, China ranked first with 21 core papers, accounting for 36.84%, followed by the United States and South Korea with 18 and 5 core papers, respectively. Among the core papers in this front, 67% pertained to organic pollutants. Most of the studies were on the catalytic transformation behavior of pollutants in the nanomaterial–water interface, followed by the microinterface behavior in minerals. Only one study focused on pollutants with regard to plant/biological microinterface behavior and transformation in the ecosystem.

In terms of citations per paper (Table 1.2.1), India was the highest (136.75), followed by South Korea, Germany, and Canada. The citations per paper of core papers from China was low (56.76), indicating a lack of innovation and influence. With regard to relevance (Figure 1.2.1), many countries have carried out comprehensive and extensive collaborative research; a strong correlation was found between China and the United States. Papers from developed countries such as the United Stated and Japan mainly focused on the catalytic degradation of pollutants, membrane treatment, interaction between pollutants, and colloids. In contrast, papers from China have focused on promoting the transformation mechanism of nanomaterials on pollutants and in situ characterization techniques. There are few basic studies in the field of microinterface behavior of combined pollution processes from China; this aspect merits further exploration and development.

There are six Chinese institutions among the top 10 research institutions that have publications in the field of microinterface behavior (Table 1.2.2). The number of core papers by the Chinese Academy of Sciences, North China Electric Power University, and Wuhan University of Technology were the highest, with three papers each. The Chinese Academy of Sciences focused on the migration and characterization of pollutants on microinterfaces, while the North China Electric Power University and Wuhan University of Technology mainly studied the effects of nanomaterials on the migration, transformation, and degradation of pollutants. In terms of citations per paper, Hong Kong Polytechnic University had the highest number of citations (87.00). The two core papers focused on the removal of pollutants by graphene materials and the removal mechanism of pollutants in the presence of nanocomposites. King Abdulaziz University and the Spanish National Research Council ranktd second and third, with their citations per paper being 85.50 and 73.00, respectively.

As shown in Figure 1.2.2, strong partnerships existed between universities and institutions with the greatest output of core papers. The Chinese Academy of Sciences showed more comprehensive cooperation relationship with other institutions, followed by the Hong Kong Polytechnic University, but there is still a lack of international cooperation and exchange between Chinese universities/institutes and foreign institutes. Future studies should aim at in-depth research on the microinterface behavior of the combined pollution process, which will provide theoretical support for the development of the corresponding pollution control technology.

Among the countries that cited core papers on specific topics (Table 1.2.3), China ranked first, followed by the United States and India. Among the 10 major institutions that cited core papers (Table 1.2.4), nine were from China, among which the Chinese Academy of Sciences, the University of the Chinese Academy of Sciences, and Tongji University were the top three.

1.2.2 New spatial pattern and controlling factors of marine biological nitrogen fixation

Nitrogen is a crucial element for life, especially in nutrient-poor ocean environments. The Redfield ratio of 6.6, as the standard of carbon nitrogen ratio (C/N), is used as the basis to identify the nutrients limiting marine productivity. However, Raymond (1993) and Walsh's (1996) study on the euphotic zone in the Atlantic and eastern Pacific Ocean showed that extrapolating nitrate consumption led to significant underestimation of organic carbon export. In fact, 34%–77% of the new production is attributed to marine nitrogen fixation. Since then, they have expanded the new spatial pattern of marine nitrogen fixation and improved the estimate of marine primary productivity. Furthermore, new spatial pattern of marine nitrogen fixation has also solved the problem of "leakage sink" in the carbon and nitrogen balance budget, which has puzzled scientists for years.

Marine nitrogen fixation could provide "new" nitrogen to the global ocean, supporting carbon uptake and sequestration. Thus, marine nitrogen fixation is approximately 140 Tg N/yr. However, many questions remain regarding the regulation mechanisms of marine nitrogen fixation, including spatial and temporal characteristics, species identification, genetic ability, adaptability, and the acquisition of nutrients for growth.

The only dominant nitrogen-fixing groups previously known were *Trichodesmium* spp. and *Richelia* sp. A wide range of studies, from genetic to ecosystem level, have revealed

Table 1.2.1 Countries with the greatest output of core papers on “microinterface behavior of combined pollution process”

No.	Country	Core papers	Percentage of core papers	Citations	Citations per paper	Mean year
1	China	21	36.84%	1 192	56.76	2016.3
2	USA	18	31.58%	1 076	59.78	2015.8
3	South Korea	5	8.77%	377	75.40	2017.8
4	Saudi Arabia	5	8.77%	349	69.80	2016.0
5	India	4	7.02%	547	136.75	2015.8
6	Germany	4	7.02%	301	75.25	2015.5
7	UK	4	7.02%	258	64.50	2017.2
8	Spain	4	7.02%	230	57.50	2015.2
9	Canada	3	5.26%	211	70.33	2016.7
10	France	3	5.26%	165	55.00	2016.3

Figure 1.2.1 Collaboration network among major countries in the engineering research front of “microinterface behavior of combined pollution process”

Table 1.2.2 Institutions with the greatest output of core papers on “microinterface behavior of combined pollution process”

No.	Institution	Core papers	Percentage of core papers	Citations	Citations per paper	Mean year
1	Chinese Academy of Sciences	3	5.26%	215	71.67	2015.3
2	North China Electric Power University	3	5.26%	211	70.33	2016.7
3	Wuhan University of Technology	3	5.26%	148	49.33	2017.3
4	Hong Kong Polytechnic University	2	3.51%	174	87.00	2018.0
5	King Abdulaziz University	2	3.51%	171	85.50	2015.5
6	Spanish National Research Council	2	3.51%	146	73.00	2014.5
7	Shanghai Jiao Tong University	2	3.51%	143	71.50	2017.0
8	Xi’an Jiaotong University	2	3.51%	142	71.00	2015.5
9	King Abdullah University of Science and Technology	2	3.51%	137	68.50	2016.0
10	Colorado School of Mines	2	3.51%	108	54.00	2016.5

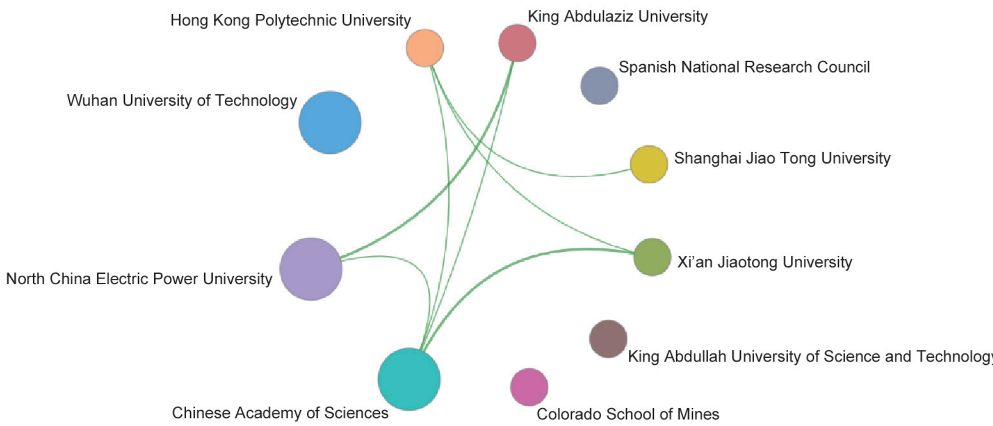

Figure 1.2.2 Collaboration network among major institutions in the engineering research front of "microinterface behavior of combined pollution process"

Table 1.2.3 Countries with the greatest output of citing papers on "microinterface behavior of combined pollution process"

No.	Country	Citing papers	Percentage of citing papers	Mean year
1	China	177	51.01%	2019.7
2	USA	39	11.24%	2019.7
3	India	28	8.07%	2019.4
4	South Korea	16	4.61%	2019.8
5	Australia	14	4.03%	2019.4
6	UK	14	4.03%	2019.8
7	France	13	3.75%	2019.5
8	Italy	12	3.46%	2019.8
9	Japan	12	3.46%	2019.5
10	Germany	11	3.17%	2019.5

Table 1.2.4 Institutions with the greatest output of citing papers on "microinterface behavior of combined pollution process"

No.	Institution	Citing papers	Percentage of citing papers	Mean year
1	Chinese Academy of Sciences	21	23.08%	2019.3
2	University of Chinese Academy of Sciences	12	13.19%	2019.0
3	Tongji University	9	9.89%	2019.7
4	South China University of Technology	8	8.79%	2020.0
5	Nankai University	7	7.69%	2019.6
6	Technological University of Malaysia	6	6.59%	2020.0
7	Zhejiang University	6	6.59%	2020.0
8	Jiangsu University	6	6.59%	2020.0
9	Hong Kong Polytechnic University	6	6.59%	2019.0
10	Harbin Institute of Technology	5	5.49%	2020.0

an increasing number of new diazotrophs, and the ability to estimate global nitrogen fixation has also improved significantly. The most striking discovery was the identification of the marine microplankton (UCYN-A, UCYN-B, UCYN-C) that, even in small size, exhibit substantial nitrogen fixation rates. These results showed that the range of biological nitrogen fixation is much wider than previously expected. Existing research has shown that biological nitrogen fixation is mainly controlled by environmental factors, such as temperature and phosphorus and iron availability. Meanwhile, global climate change and human activities also affect nitrogen fixation. For example, in the years experiencing El Niño–Southern Oscillation (ENSO) events, different spatial patterns of global marine biological nitrogen fixation are observed.

Some scholars have comprehensively studied marine nitrogen fixation and its controlling factors by establishing biogeochemical and ecological models. However, results of marine field observations are significantly different from those predicted by the models; consequently, spatial patterns of marine nitrogen fixation are characterized by discrepancies. Therefore, more systematic research is needed that involves combining field observations, laboratory analyses (e.g., molecular biology, genomics, isotopes), satellite remote sensing monitoring, and other methods. Moreover, combined with global and regional environmental changes and biogeochemical models, further studies on the spatial distribution and regulation mechanism of marine biological nitrogen fixation can be conducted. Research on the spatiotemporal expansion of biological nitrogen-fixing activity and the discovery of new diazotrophs and joint nitrogen fixation has greatly expanded our understanding of marine continental shelf ecosystems and coastal marine wetlands. The assessment of marine primary productivity and carbon and nitrogen cycle stimulate the development of marine ecological engineering, marine aquaculture, and geoengineering. In addition, research on nitrogen fixation by chemotrophs in deep-sea cold springs coupled with that on hydrothermal ecosystems can provide a new direction for the cognition of spatial-temporal patterns of marine biological nitrogen fixation.

Table 1.2.5 shows the main countries that have published the core papers on “new spatial patterns and controlling factors of marine biological nitrogen fixation.” The United States ranks first in the proportion of both the number of papers published and citations, leading by a large margin. This indicates that the United States holds significant research advantage in this field. There is extensive cooperation between the major output countries (Figure 1.2.3). Table 1.2.6 shows the main institutions with the most core papers in this research front. The top 10 institutions are predominantly concentrated in the United States. According to the cooperation network of the major institutions (Figure 1.2.4), extensive collaboration can be observed.

China ranks third in terms of the citations per paper of its core papers (Table 1.2.7). The Chinese Academy of Sciences and Xiamen University ranked third and ninth, respectively, in the rankings of institutions with the greatest output of citing papers (Table 1.2.8).

1.2.3 Precise dietary regulation technology based on intestinal flora intervention

The human intestine contains trillions of microbial communities. The intestine is the site of digestion and nutrient absorption and is also an important immune organ. The intestinal flora and human have a symbiotic relationship. The intestinal flora and its metabolites directly affect the health of the host, and play a potential role in protecting the hosts from intestinal or immune system diseases, obesity, and diabetes. The composition and function of the intestinal flora are determined by the genetic background and external factors; among the latter, diet is one of the most critical factors. Diet affects the composition of the intestinal flora and its metabolites through alterations in the type of nutrients and nutrient balance, and regulates the stability of the microorganism’s microecology, thus affecting human health.

The human gut microbiota varies greatly among individuals, emphasizing the need for a planned optimal diet. The temporal differences in the intestinal flora of the human body and its universality in different regions have been identified to better understand the biological impacts of specific intervention strategies for the gut microbiota. At the same time, aspects such as the influence of food on the intestinal microbiota and the specific microbiota interacting with it have been comprehensively explored to discuss the relationship between human intestinal microbiota and dietary patterns, structure, and disease occurrence and development.

With the development of the social economy, people are currently regulating the intestinal flora and its metabolic spectrum through their diet. The interaction network diagram

Table 1.2.5 Countries with the greatest output of core papers on "new spatial pattern and controlling factors of marine biological nitrogen fixation"

No.	Country	Core papers	Percentage of core papers	Citations	Citations per paper	Mean year
1	USA	17	65.38%	946	55.65	2015.3
2	Germany	6	23.08%	269	44.83	2016.0
3	Netherlands	4	15.38%	249	62.25	2016.5
4	UK	4	15.38%	220	55.00	2016.5
5	Japan	4	15.38%	180	45.00	2015.0
6	South Africa	2	7.69%	166	83.00	2016.0
7	Switzerland	2	7.69%	145	72.50	2014.0
8	Canada	2	7.69%	109	54.50	2017.0
9	Italy	2	7.69%	109	54.50	2017.0
10	India	2	7.69%	99	49.50	2015.5

Figure 1.2.3 Collaboration network among major countries in the engineering research front of "new spatial pattern and controlling factors of marine biological nitrogen fixation"

Table 1.2.6 Institutions with the greatest output of core papers on "new spatial pattern and controlling factors of marine biological nitrogen fixation"

No.	Institution	Core papers	Percentage of core papers	Citations	Citations per paper	Mean year
1	University of California, Santa Cruz	4	15.38%	188	47.00	2014.8
2	University of Tokyo	4	15.38%	180	45.00	2015.0
3	University of Southern California	3	11.54%	154	51.33	2015.0
4	University of California, Irvine	3	11.54%	132	44.00	2017.0
5	University of Washington	2	7.69%	157	78.50	2014.5
6	Woods Hole Oceanographic Institution	2	7.69%	119	59.50	2014.5
7	University of Hawaii at Manoa	2	7.69%	118	59.00	2017.5
8	University of Liverpool	2	7.69%	111	55.50	2017.0
9	Utrecht University	2	7.69%	109	54.50	2017.0
10	University of California, Los Angeles	2	7.69%	99	49.50	2015.5

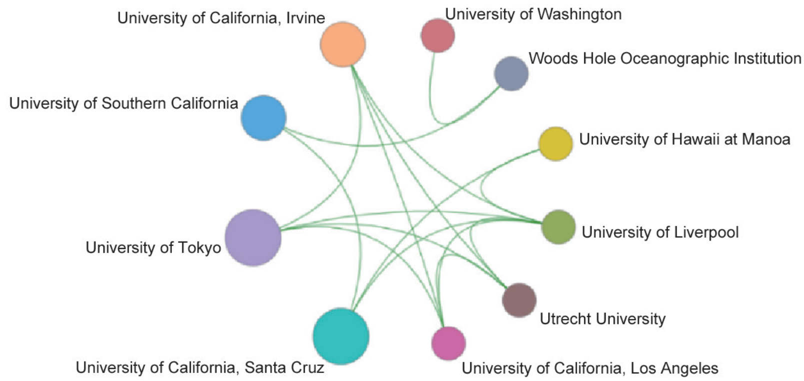

Figure 1.2.4 Collaboration network among major institutions in the engineering research front of “new spatiatial pattern and controlling factors of marine biological nitrogen fixation”

Table 1.2.7 Countries with the greatest output of citing papers on “new spatial pattern and controlling factors of marine biological nitrogen fixation”

No.	Country	Citing papers	Percentage of citing papers	Mean year
1	USA	473	32.51%	2017.8
2	Germany	174	11.96%	2017.6
3	China	148	10.17%	2018.1
4	UK	147	10.10%	2017.8
5	France	129	8.87%	2017.8
6	Australia	109	7.49%	2018.1
7	Canada	72	4.95%	2018.1
8	Japan	71	4.88%	2018.0
9	Spain	47	3.23%	2017.8
10	India	45	3.09%	2018.0

of different ingredients in food and intestinal flora has been constructed, which is the key and basic work for achieving predefined nutritional goals, revealing the structure–function relationship of microbiota, and promoting research and development of microbiota-directed foods. This network has broad prospects in the development of safe, reliable, nutritious, healthy, and beneficial precision diet control technology that people can afford.

Table 1.2.9 shows the main output countries with core papers in “precise dietary regulation technology based on intestinal flora intervention”. The United States ranks first in both the number of core papers and the citations per paper, indicating that it has great research advantages in this respect. The collaboration among the major output countries (Figure 1.2.5) has been extensive. Table 1.2.10 shows the main output institutions with core papers in this engineering research front. Wageningen University ranks first in terms of number and percentage of core papers. According to the main inter-agency cooperation network (Figure 1.2.6), Washington University has conducted research and development independently, while other institutions have cooperative relationships.

The main countries with the greatest output of citing papers on this research front are shown in Table 1.2.11. While China ranks second in both the number and percentage of citing papers. The main institutions with the greatest number of citing papers are listed in Table 1.2.12. Compared with other institutions, Harvard University has a significantly higher number and percentage of citing papers. The Chinese Academy of Sciences ranks third among the institutions with the greatest output of citing papers.

Table 1.2.8 Institutions with the greatest output of citing papers on "new spatial pattern and controlling factors of marine biological nitrogen fixation"

No.	Institution	Citing papers	Percentage of citing papers	Mean year
1	University of California, Santa Cruz	50	12.92%	2017.0
2	University of Washington	46	11.89%	2017.7
3	Chinese Academy of Sciences	41	10.59%	2017.6
4	University of Southern California	35	9.04%	2017.7
5	University of Bremen	32	8.27%	2017.9
6	Woods Hole Oceanographic Institution	32	8.27%	2017.3
7	Max Planck Inst Marine Microbiol	31	8.01%	2017.7
8	Princeton University	31	8.01%	2017.9
9	Xiamen University	30	7.75%	2018.1
10	University Toulon & Var	30	7.75%	2017.6

Table 1.2.9 Countries with the greatest output of core papers on "precise dietary regulation technology based on intestinal flora intervention"

No.	Country	Core papers	Percentage of core papers	Citations	Citations per paper	Mean year
1	USA	25	31.25%	4 180	167.20	2015.4
2	UK	18	22.50%	3 328	184.89	2014.7
3	Italy	15	18.75%	2 123	141.53	2015.4
4	Netherlands	13	16.25%	2 334	179.54	2014.2
5	Belgium	9	11.25%	1 477	164.11	2014.8
6	France	8	10.00%	1 877	234.62	2014.8
7	Sweden	6	7.50%	1 669	278.17	2015.0
8	Denmark	6	7.50%	1 317	219.50	2014.5
9	Germany	6	7.50%	1 013	168.83	2015.5
10	China	6	7.50%	747	124.50	2016.0

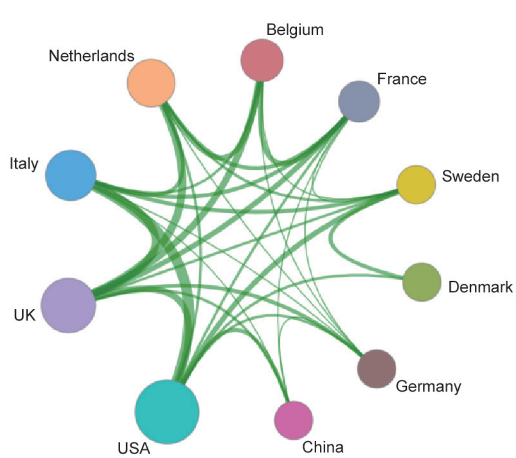

Figure 1.2.5 Collaboration network among major countries in the engineering research front of "precise dietary regulation technology based on intestinal flora intervention"

Table 1.2.10 Institutions with the greatest output of core papers on “precise dietary regulation technology based on intestinal flora intervention”

No.	Institution	Core papers	Percentage of core papers	Citations	Citations per paper	Mean year
1	Wageningen University	8	10.00%	1 193	149.12	2014.0
2	French National Institute for Agricultural Research	7	8.75%	1 781	254.43	2014.6
3	University of Copenhagen	6	7.50%	1 317	219.50	2014.5
4	Catholic University of Louvain	6	7.50%	1 189	198.17	2014.8
5	University of Bologna	6	7.50%	860	143.33	2014.7
6	University of Gothenburg	4	5.00%	1 528	382.00	2015.0
7	Washington University	4	5.00%	713	178.25	2015.5
8	University of Reading	4	5.00%	661	165.25	2013.8
9	University of Helsinki	4	5.00%	555	138.75	2014.2
10	University of Aberdeen	3	3.75%	759	253.00	2013.7

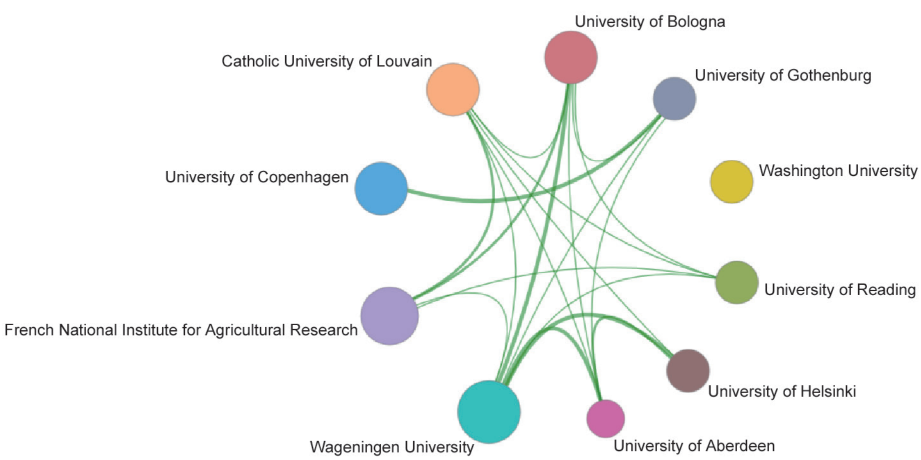

Figure 1.2.6 Collaboration network among major institutions in the engineering research front of “precise dietary regulation technology based on intestinal flora intervention”

Table 1.2.11 Countries with the greatest output of citing papers on “precise dietary regulation technology based on intestinal flora intervention”

No.	Country	Citing papers	Percentage of citing papers	Mean year
1	USA	2 566	28.14%	2017.8
2	China	1 710	18.75%	2018.4
3	UK	762	8.36%	2017.6
4	Italy	752	8.25%	2017.7
5	Spain	575	6.31%	2017.8
6	Germany	549	6.02%	2017.8
7	France	514	5.64%	2017.5
8	Canada	487	5.34%	2017.5
9	Netherlands	471	5.17%	2017.5
10	Australia	422	4.63%	2017.9

Table 1.2.12 Institutions with the greatest output of citing papers on "precise dietary regulation technology based on intestinal flora intervention"

No.	Institution	Citing papers	Percentage of citing papers	Mean year
1	Harvard University	227	16.31%	2017.8
2	University of Copenhagen	175	12.57%	2017.8
3	Chinese Academy of Sciences	149	10.70%	2018.3
4	University College Cork	127	9.12%	2018.0
5	Kings College London	116	8.33%	2017.4
6	Wageningen University	106	7.61%	2016.9
7	University of Bologna	104	7.47%	2017.5
8	University of Gothenburg	100	7.18%	2017.2
9	Shanghai Jiao Tong University	100	7.18%	2017.9
10	University of Illinois	95	6.82%	2017.9

2 Engineering development fronts

2.1 Trends in top 10 engineering development fronts

The top 10 engineering development fronts in the field of environmental engineering are summarized in Table 2.1.1. These include the subfields of environmental science engineering, meteorological science engineering, marine science engineering, food science engineering, textile science engineering, and light industry science engineering. The number of patents between 2014 and 2019 related to these individual topics is summarized in Table 2.1.2.

(1) Synergistic remediation technologies for soil–water pollution

An intimate exchange of substances occurs between the soil and groundwater. It is imperative to control and remediate pollution from soil to groundwater to support sustainable development. Pollution of surface water, soil, and groundwater occurs around industries or refineries such as petroleum, chemical engineering, and smelting. The development of synergistic remediation technologies for soil–water pollution is important to ensure the safety of soil and groundwater. Among the main patents of this development frontier, *in situ* and *ex situ* remediation technologies account for 67.3% and 32.7%, respectively. The *in situ* remediation technologies include specialized devices for injecting and mixing remediation reagents; combined remediation employing phytoextraction, plant-earthworms, or plant-microbes; electrokinetic remediation combined with permeable reactive barriers; adsorption using activated carbon or biochar; and bioventing. The patents for devices used for injecting and mixing remediation reagents, which involve specific technologies such as high-pressure injection, oscillation, and sprinkling, dominate the developed *in situ* remediation technologies. Most of the developed *ex situ* remediation technologies are combinations of multiple techniques. Among these, the dominant patents are for the devices used for excavation, transportation, sorting, pulverization, mixing, agitation of soil, soil rinsing/filtration along with those used for the treatment of the used eluent, thermodesorption along with the adsorption/condensation of the vapor, chemical oxidation and advanced oxidation, and biological filters. The main target pollutants of *in situ* and *ex situ* synergistic remediation treatments include petroleum hydrocarbons, halohydrocarbons, and heavy metals.

Chinese patents account for over 99% in this field, demonstrating that China has paid sufficient attention to the development of synergistic remediation technologies for soil–water pollution. However, most of the developed patents focus on combined devices or systems for simultaneous remediation of soil and water with individual technologies. Practical technologies for highly synergistic remediation of soil and water are still in great demand. A promising field of research in the future is the development of highly efficient technologies for synergistic soil–water remediation based on partitioning, transport, and transformation of different pollutants between soil and water.

Table 2.1.1 Top 10 engineering development fronts in environmental and light textile engineering

No.	Engineering development front	Published patents	Citations	Citations per patent	Mean year
1	Synergistic remediation technologies for soil–water pollution	357	635	1.78	2017.1
2	Microbial agents for wastewater treatment	711	845	1.19	2017.2
3	Collaborative treatment of multi-media pollution	1 000	3 293	3.29	2016.5
4	Airborne pathogen detector system and method	1 000	29 308	29.31	2013.6
5	Natural disaster prevention, early warning, and restoration decision-making project	1 000	13 830	13.83	2016.0
6	Nanocomposite marine antifouling coatings	214	384	1.79	2017.2
7	Offshore wave power generation technology	250	648	2.59	2016.4
8	Food intelligent manufacturing technology	624	4 506	7.22	2016.0
9	Carbon-fiber-based electronic devices	1 000	12 138	12.14	2015.8
10	Ultra-low emission technology for pulping and papermaking pollution	1 000	3 263	3.26	2017.2

Table 2.1.2 Annual number of core patents published for the top 10 engineering development fronts in environmental and light textile engineering

No.	Engineering development front	2014	2015	2016	2017	2018	2019
1	Synergistic remediation technologies for soil–water pollution	23	29	34	124	63	76
2	Microbial agents for wastewater treatment	45	55	89	123	158	215
3	Collaborative treatment of multi-media pollution	79	93	127	185	190	231
4	Airborne pathogen detector system and method	93	97	97	93	86	103
5	Natural disaster prevention, early warning, and restoration decision-making project	102	96	150	171	173	162
6	Nanocomposite marine antifouling coatings	3	9	30	56	76	34
7	Offshore wave power generation technology	41	26	21	36	39	63
8	Food intelligent manufacturing technology	42	68	60	108	138	109
9	Carbon-fiber-based electronic devices	75	80	73	176	104	266
10	Ultra-low emission technology for pulping and papermaking pollution	14	42	146	250	254	247

(2) Microbial agents used for wastewater treatment

With the rapid development of modern industrialization, a large amount of emerging and refractory contaminants have been discharged into the environment. However, the elimination of these pollutants by conventional biochemical processes is very difficult. Microbial agents refer to the microbial communities in liquid or powder form designed to enhance the performance of wastewater treatment systems. Microbial agents, comprised of naturally existing bacteria or artificial ones with specific metabolic functions, can be produced through microbiota cultivation. By adding specific microbial agents into the wastewater treatment system, the rapid degradation of target contaminants can be achieved. These agents have obvious advantages of being user-friendly, cost-effective, widely applicable, and do not cause secondary pollution. Furthermore, they are compatible with the existing water treatment facilities. In recent years, some progress has been observed in the development of single-component microbial agents, and such agents have been widely used to treat wastewater from domestic sewage, eutrophic water bodies, livestock farms, landfill leachate, and industrial sources. Theoretically, composite microbial agents should perform better than single-component microbial agents and should have a higher application potential as they are composed of various functional microbiota. However, maintaining the stability of such agents challenging because of the complex interactions among the different microorganisms and their metabolites. Therefore, to improve the efficacy of wastewater treatment, it is essential to explore the interaction mechanisms of microbial communities, optimize the selection of bacteria, and enhance the stability of composite microbial agent populations. Product serialization and standardization should also be emphasized to increase the applicability and cost-efficiency of such agents.

(3) Collaborative treatment of multi-media pollution

The composite effect and collaborative control of environmental pollution by different media are at the forefront of scientific and technological problems. The core problem of regional environmental quality improvement is the coordinated control of multi-media (i.e., air–water–soil) composite pollution. There is a complex nonlinear relationship between source emissions, environmental concentrations of pollutants, and effects of regional composite pollution. The exposure level to multi-media compound pollutants is generally high, with complex health effects. Nitrogen and phosphorus deposition in the atmosphere aggravate eutrophication of water bodies, and mercury deposition from coal combustion poses health risks to entire ecosystems. During sewage and sludge treatment, several pollutants, such as odor gas, biological aerosols, and greenhouse gases, are released, adversely impacting the air environment. Excessive quantities of nitrogen fertilizers in soil, caused by improper application methods, enter the atmosphere in the form of ammonia and nitrogen oxides, which not only produces odor but also increases the greenhouse effect. Chemical fertilizer application and livestock breeding are important sources of ammonia emissions, which, along with $PM_{2.5}$ induce haze formation. In addition, agricultural non-point source pollution is an important source of lake eutrophication. Therefore, promotion of theoretical innovation, breakthrough in non-progressive technology, and facilitation of engineering technology implementation of multi-media pollution collaborative treatment of air, surface water, soil, and groundwater, are important. Progress can be achieved by focusing on key problems, developing monitoring and simulation technologies for large-scale environmental processes, improving clean production and risk control technologies involved in the entire process, and establishing comprehensive environmental treatment technologies and system solutions at a regional scale. A multi-media pollution control theory and technology system, with an intelligent supervision system, to achieve a new pattern of multi-media environmental security, should also be undertaken.

(4) Airborne pathogen detector system and method

In recent decades, humans have been facing threats by airborne diseases. Airborne pathogens are microorganisms that can invade susceptible hosts and cause disease; these mainly include viruses (e.g., COVID-19, H1N1 influenza, SARS) and bacteria (e.g., *Mycobacterium tuberculosis*, *Streptococcus pneumoniae*). Currently, the detection of pathogens relies on clinical observations and accurate detection of samples obtained from the patients. These processes are time-consuming and the detection range is limited, which hampers the requirement for rapid disease control and prevention.

Detecting pathogens directly from the air is an ideal method for the prevention and control of airborne diseases. However, the concentration of respirable pathogens in the air can be low, requiring sensitive detectors. In addition, the interference caused by saliva and dust particles, which are scattered and heterogeneous, poses a challenge to the accurate detection of pathogens. Another major obstacle to airborne pathogen detection is processing and automation. The detection process includes air sampling and detection by a sensor, which is usually a time-consuming manual process, making it difficult to obtain real-time feedback.

To achieve rapid prevention and control of airborne diseases, it is necessary to explore integrated, highly sensitive, low-cost detector systems and methods that can be used widely for rapid and accurate detection of in the air. The realization of this goal requires the urgent development and integration of multiple detection methods as well as automated detection, processing, and data transmission systems.

(5) Natural disaster prevention, early warning, and restoration decision-making project

The total number of global natural disasters has increased significantly over the past two decades, especially the “shocking” increase of climate-related disasters. Specifically, a total of 7348 natural disasters have been recorded globally between 2000 and 2019, leading to 1.23 million deaths, with almost 4 billion people being affected, and up to 3 trillion USD endured as economic losses.

China is one of the countries that experiences the most serious natural disasters; they are in frequent occurrence, have wide distribution, and result in massive losses to life and property. The frequency and intensity of extreme weather and climate events (e.g., El Niño, drought, floods, thunderstorms, hail, storms, high-temperature weather, sandstorms) caused by climate change have increased significantly in the 20th century, which directly endangers the development of China's national economy. With the rapid growth of China's economy, the absolute economic value of losses, caused by weather and climate disasters, for example, the large-scale floods in 2020, which severely affected numerous lives, has also increased.

Therefore, the development of natural disaster prevention, early warning, and post-disaster recovery decision-making projects is particularly important in disaster prevention and mitigation. We should adhere to the basic principle of "prevention first"; place "disaster monitoring," "forecasting," and "early warning" in a prominent position, and provide early warning information to society, including vulnerable communities. To address these, we should rely on science and technology and strengthen scientific research and technological development, adopt and promote advanced monitoring technologies and facilities, and develop emergency response plans.

(6) Nanocomposite marine antifouling coatings

Marine biological fouling has caused great harm to the coastal regions and transportation and fisheries industries. According to statistics, the annual economic loss caused by biological fouling in the United States amounts to 700 million USD, while losses in the United Kingdom amount to 50 million pounds per year. In recent years, nanocomposite marine antifouling materials have attracted the attention of researchers in several countries as new antifouling coatings that have the potential to replace organic tin antifouling coatings. Nanocomposite marine antifouling materials are modified coatings characterized by high hydrophobicity, low surface energy, and low polarity.

The current research directions of marine antifouling coatings include the development 1) that contain nanometer components that are resistant to contamination, 2) wherein nanometer components are photocatalytically sterilized and the coatings act as shields against ultra violet, 3) that contain nanometer components that prevent biological attachment, and 4) that comprise of special acting nanomaterials (such as self-polishing function, hydrophobic function).

Solving the problem of the stable dispersion and compatibility of nanomaterials in antifouling coatings is important in addition to developing marine antifouling coatings and nanocomposite marine antifouling coatings worldwide.

(7) Offshore wave power generation technology

Wave power generation technology uses wave energy devices to convert wave energy into mechanical energy and finally into electrical energy. The technology is progressing toward offshore wave energy development with a higher production capacity than the shore-based power generation devices.

Offshore wave energy converters are mainly hydraulic and of direct-drive type. A direct-drive wave energy converter device can generate electricity directly, and the energy conversion process does not need a gearbox. It has the advantages of high reliability and low maintenance cost. Hence, it has development prospects in offshore high-power grid-connected applications. At present, the main technical directions of offshore wave power generation technology include the structural design of direct-driven wave energy converter, power capture and control technology, and power fluctuation treatment technology.

A linear generator is the core energy conversion device of a direct-driven wave energy converter system. Improving the reliability and energy conversion efficiency of the generator, simplifying the structure of the composite linear generator, and reducing the device volume are important development directions for direct-drive wave energy converter technology. The development of high-performance linear generators suitable for low-speed and high-thrust wave power generation is key in promoting direct-drive wave energy converter systems. In addition, superconducting materials have great potential for applications in wave power generation.

(8) Food intelligent manufacturing technology

The food industry is an important traditional livelihood industry and acts as a pillar industry for the national economy. With the rapid development of information technology, big data, cloud computing, Internet of Things, and other emerging technologies are being increasingly applied to the food industry, and research and development encompassing the entire industrial chain development model of the food industry, the process of production-to-sales is undergoing profound changes. In recent years, widespread application of intelligent manufacturing in the food industry has provided a direction for promoting the transformation and upgrade of our food industry. Intelligent manufacturing has achieved remarkable results in ensuring product quality and safety. Regarding food safety, smart factories use the Internet of Things and other monitoring technologies to strengthen information management services, improve the controllability of the production process, and reduce manual intervention in the production line. At the same time, the smart factories can collect and analyze data independently, realize coordination and cooperation between humans and machines, and ensure the safe production of food. Furthermore, product optimization is also promoted via the use of intelligent manufacturing technology. Digital indicators can be developed in intelligent workshops by collecting, analyzing, and continuously optimizing the key indicators of each production process according to the state of the intermediate materials and the taste experience of the final product; the production process is controllable, product has stability, and product quality is greatly improved. Finally, the intelligent production system improves production efficiency. The system adopts an integrated design concept, optimizes the complex processing methodology, compresses production links, and automates production using information technology, scheduling algorithms, automatic identification, and other technologies, with high speed and precision.

(9) Carbon-fiber-based electronic devices

Carbon-fiber-based electronic devices are a series of devices constructed with fiber membranes, yarns, and fabrics that use using carbon-based fibers (that have high flexibility and integrity) as the basic unit. The diameter of the carbon-based fibers ranges from a few hundred nanometers to tens of micrometers; this property can be made use of in customizing the structure of the device from micro to macro. Currently, the main technical directions pertaining to the carbon-fiber-based electronic devices include the development of flexible fiber-based energy storage devices, flexible fiber-based sensors, and flexible smart wearable textiles, among others. More specifically, devices such as carbon-fiber-based solar cells, carbon-fiber-based supercapacitors, flexible fuel cells, carbon-fiber-based piezoelectric sensors, and carbon-fiber-based friction generators, are being progressively developed. Owing to the efficient ion and electron transport properties and outstanding flexibility of carbon-fiber-based textiles, the carbon-fiber-based electronic devices are being developed to improve performance, lightness, thinness, flexibility, integration, and resistance to wear.

(10) Ultra-low emission technology for pulping and papermaking pollution

The pulping and papermaking industry is an important basic raw material industry. With the rapid development of this industry, the environmental pollution caused by pulping and papermaking has become increasingly serious. Therefore, developing ultra-low emission technologies for pollution control from pulping and papermaking is the key to simultaneously meet social demands and the need for green and sustainable development.

The ultra-low emission technology refers to the utilization of deep treatment systems to achieve ultra-low emission of pollutants and meet the emission standards. The currently existing ultra-low emission technologies include advanced oxidation, membrane separation, membrane bioreactor activated carbon adsorption and its comprehensive application, sand filtration, magnetic finishing, magnetization–enzyme-like catalytic condensation, oxidation ponds, constructed wetlands, and other technologies. However, the current ultra-low emission technologies of pulping and papermaking pollution still lack practicability and economy. Consequently, it is an important research focus for the pulping and papermaking industry to develop mature, stable, and cost-effective ultra-low emission technologies.

2.2 Interpretations for three key engineering development fronts

2.2.1 Airborne pathogen detector system and method

In recent decades, humans have been facing the threats of various airborne diseases, such as COVID-19, H1N1, and SARS. Airborne pathogens are microorganisms, mainly viruses and bacteria, that can invade susceptible hosts and cause diseases. These pathogens spread by droplets, droplet nuclei, and dust. At present, pathogen detection relies on clinical observation and accurate detection samples obtained from the patients. These processes are time-consuming and the detection range is limited, which hinders the need for rapid disease control and prevention.Detecting pathogens directly from the air is an ideal method for the prevention and control of airborne diseases. However, the concentration of respirable pathogens in the air can be low, requiring sensitive detectors. In addition, the interference caused by saliva and dust particles poses a challenge to the accurate detection of pathogens. The size of these aerosol particles varies with the manner in which they are discharged; speaking: (33.5 ± 5) μm, breathing: (127.3 ± 20) μm, coughing: 1–40 μm, sneezing: 2–16 μm.

Another major obstacle to airborne pathogen detection is processing and automation. The detection process mainly includes air sampling and sensor detection. Several studies exist on these two aspects individually; however, few studies have focused on the integration of both processes. The loading work from sampling to detection is usually manual, making it difficult to realize the function of continuous sampling, automation, and real-time feedback.

To achieve rapid prevention and control of airborne diseases, it is necessary to explore integrated, highly sensitive, low-cost detector systems and methods that can be widely applied for rapidly and accurately detecting pathogens in the air. Real-time polymerase chain reaction, nucleic acid, mass spectrometry, colloidal gold, laser particle counting, loop-mediated isothermal amplification, enzyme-linked immunosorbent assay, and real-time quartz crystal microbalance technology are among the most efficient detection methods. In addition, it is also necessary to design an integrated, automated detection process and an intelligent data transmission system to achieve continuous and real-time airborne pathogen detection.

From a global perspective, the United States ranks first in terms of the number of patent publications and citations of "airborne pathogen detector systems and methods", as shown in Table 2.2.1. China's core patent disclosures are listed at the second place, accounting for 7.20%, while in terms of citations, it ranks sixth (with 2.01%). The number of patent publications of the United Kingdom, Germany, Canada, and other countries is less than that of China, but the citations per patent far exceeds that of China. This indicates that although the number of studies and innovations for airborne pathogen detection in China is increasing, their influence is still insufficient. The cooperation network diagram (Figure 2.2.1) shows extensive international collaboration among countries. In addition to the closest cooperation with the United States, Chinese scholars also cooperate with Swiss and British institutions.

Table 2.2.2 shows the main institutions producing core patents in this engineering research front. Among them, Bizmodeline from South Korea has 28 core patent disclosures, ranking first among all institutions and, while the average citations per patent is only 0.04. The institution with the highest average citations per patent for publishing core patents is AbbVie Inc. from the United States, which accounts for 1.70% of publications, with the citations per patent reaching 5.78%. The citations per patent of Parion Sciences, with the same number of patent publications as Abbvie, is only 0.68%. The core patents published by Abbott Laboratories also have a significant influence, with the average number of citations reaching 104.13. The institution with the most citations is Dana-Farber Cancer Institute; although its number of published patents only accounts for 1.10%, the average number of citations is 138.64. The cooperation network of major international institutions in Figure 2.2.2 shows the institutions with the most frequent cooperation relationship are AbbVie Inc. and Abbott Laboratories. In addition, Dana-Farber Cancer Institute cooperates with Harvard University and Novartis AG. In the future, China should further enhance its cooperation with other international institutions. Besides the United States, China ought to cooperate with countries with greater core patent influence, such as the United Kingdom, Germany, India, and Switzerland. The principle of "quantity first" in scholar's performance assessment should be revised, and relevant assessments of the influence and innovation should be supplemented to encourage scientific research institutions to pay more attention to the quality of the research, and to promote the sustainable development of the relevant disciplines.

2.2.2 Natural disaster prevention, early warning, and restoration decision-making project

In recent decades, the frequency and intensity of extreme weather and climate events (e.g., El Niño, drought, floods, thunderstorms, hail, storms, high-temperature weather, sandstorms) caused by climate change have increased significantly, which has caused serious effects and great losses to society, the economy, and people's lives. According to statistics, between 1991 and 2000, the yearly average number of people affected by meteorological and hydrological disasters worldwide was 211 million, which is seven times the number of people affected by wars and conflicts. Asia is the continent most frequently hit by natural disasters.

Table 2.2.1 Countries with the greatest output of core patents on "airborne pathogen detector system and method"

No.	Country	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	USA	620	62.00%	23 736	80.99%	38.28
2	China	72	7.20%	589	2.01%	8.18
3	South Korea	56	5.60%	155	0.53%	2.77
4	UK	48	4.80%	1 758	6.00%	36.63
5	Germany	47	4.70%	2 508	8.56%	53.36
6	Canada	40	4.00%	783	2.67%	19.58
7	Switzerland	32	3.20%	856	2.92%	26.75
8	Japan	31	3.10%	506	1.73%	16.32
9	Australia	19	1.90%	198	0.68%	10.42
10	India	16	1.60%	541	1.85%	33.81

Figure 2.2.1 Collaboration network among major countries in the engineering development front of "airborne pathogen detector system and method"

Table 2.2.2 Institutions with the greatest output of core patents on "airborne pathogen detector system and method"

No.	Institution	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	Bizmodeline Co., Ltd.	28	2.80%	1	0.00%	0.04
2	AbbVie Inc.	17	1.70%	1 695	5.78%	99.71
3	Parion Sciences	17	1.70%	200	0.68%	11.76
4	Abbott Laboratories	16	1.60%	1 666	5.68%	104.13
5	Bristol-Myers Squibb Company	14	1.40%	1 376	4.69%	98.29
6	Dana-Farber Cancer Institute	11	1.10%	1 525	5.20%	138.64
7	ICU Medical, Inc.	10	1.00%	336	1.15%	33.60
8	Harvard University	8	0.80%	913	3.12%	114.13
9	Novartis AG	8	0.80%	425	1.45%	53.13
10	3M Innovative Properties Company	8	0.80%	311	1.06%	38.88

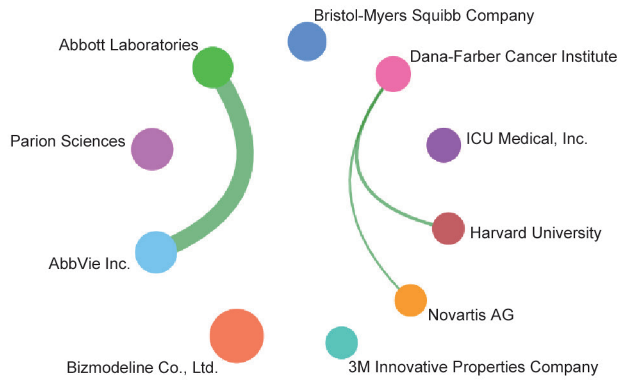

Figure 2.2.2 Collaboration network among major institutions in the engineering development front of “airborne pathogen detector system and method”

The economic losses caused by global climate change and related extreme weather events have increased by 10 times in the past 40 years. Approximately 34 million hectares (more than 500 million acres) of China’s farmland are affected by various weather and climate disasters every year. About 600 million people have suffered major disasters such as drought, rainstorms, floods, and tropical storms. The annual mean economic losses caused by weather and climate disasters account for approximately 3%–6% of the GDP. Secondary disasters caused by changes in weather and climate result in more serious economic losses.

Many effective measures have been taken by people to prevent natural disasters and reduce their impacts. We should adhere to the basic principle of “prevention first” and prioritize monitoring, forecasting, and early warning measures as well as provide effective early warning information to the society, including vulnerable communities. Meteorological disasters are public emergencies that can be predicted accurately long in advance. Strengthening the short-term forecasts, developing early warning signals, and releasing meteorological warning information are important for improving the level of disaster prevention and mitigation. We should rely on science and technology and strengthen scientific research and technological development, adopt and promote advanced monitoring technologies and facilities, and develop emergency response plans to support post-disaster recovery decision-making.

The main countries with the greatest output of core patents on this development front are shown in Table 2.2.3. China ranked first in the number of core patent disclosures, South Korea second, and the United States third. However, the average number of citations of China is only 1.78. This indicates that although China has many core patents in this field, these lack technical innovation and influence; hence, further improvements are required in this field. The collaboration network on “natural disaster prevention, early warning, and recovery decision project” (Figure 2.2.3) shows that the United States has collaboration with Colombia and Switzerland, while China has little collaboration with other countries.

The main institutions with the greatest output of core patents are listed in Table 2.2.4. The top two institutions with the hightest citations of their patents are Chengdu University of Technology (11) and State Farm Mutual Automobile Insurance (7), which are located in China and the United States, respectively. Figure 2.2.4 presents the collaboration network among these institutions. Collaboration in this development front is very weak, and only Chengdu University of Technology, Jiangxi Meteorological Observatory, and Emergent Geohazards Center of Jiangxi Province have collaboration with each other.

2.2.3 Carbon-fiber-based electronic devices

The demand for flexibility has promoted the development of carbon-fiber-based electronic devices. carbon-fiber-based materials can adapt to different working environments and usage requirements because of their excellent flexibility, outstanding conductivity and strength. The new generation of portable electronic equipment, human detectors,

Table 2.2.3 Countries with the greatest output of core patents on "natural disaster prevention, early warning, and restoration decision-making project"

No.	Country	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	China	218	60.56%	387	47.43%	1.78
2	South Korea	85	23.61%	73	8.95%	0.86
3	USA	20	5.56%	299	36.64%	14.95
4	Japan	20	5.56%	40	4.90%	2.00
5	Colombia	16	4.44%	7	0.86%	0.44
6	Switzerland	1	0.28%	24	2.94%	24.00
7	Belgium	1	0.28%	10	1.23%	10.00
8	Sweden	1	0.28%	2	0.25%	2.00
9	Canada	1	0.28%	1	0.12%	1.00
10	Germany	1	0.28%	0	0.00%	0.00

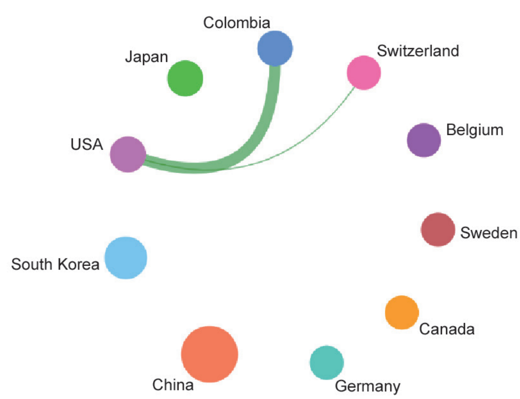

Figure 2.2.3 Collaboration network among major countries in the engineering development front of "natural disaster prevention, early warning, and restoration decision-making project"

Table 2.2.4 Institutions with the greatest output of core patents on "natural disaster prevention, early warning, and restoration decision-making project"

No.	Institution	Country	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	Chengdu University of Technology	China	7	1.94%	11	1.35%	1.57
2	State Farm Mutual Automobile Insurance	USA	7	1.94%	7	0.86%	1.00
3	Heilongjiang Zhenmei Radio Communication Equipment Co., Ltd.	China	6	1.67%	6	0.74%	1.00
4	HOCHIKI	Japan	5	1.39%	0	0.00%	0.00
5	State Grid Corporation of China	China	4	1.11%	7	0.86%	1.75
6	Chengdu Wanjiang Gangli Technology Company	China	4	1.11%	5	0.61%	1.25
7	Electronics and Telecommunications Research Institute	South Korea	4	1.11%	1	0.12%	0.25
8	Jiangxi Meteorological Observatory	China	4	1.11%	0	0.00%	0.00
9	Emergent Geohazards Center of Jiangxi Province	China	4	1.11%	0	0.00%	0.00
10	Institute of Mountain Hazards and Environment, Chinese Academy of Sciences	China	3	0.83%	3	0.37%	1.00

and environmental sensors can make full use of these characteristics to make fully flexible devices, which will play an important role in future wearable electronic equipment and smart clothing.

In terms of major countries with the greatest output of core patents on this front (Table 2.2.5), the main patents have been produced in China, Japan, and the United States. Among them, the number of core patents published by China accounts for 32.30%, and the citations per patent is 1.42. The total number of core patents published by the United States accounts for 15.60%, and the citations per patent is 44.56. Japan, Canada, France, the United States, and the Netherlands have cooperated relatively closely in this field, while China has shown an independent research and development capability (Figure 2.2.5). In terms of output institutions, LG Chemical Ltd., Toray Industries, Inc., and Saudi Basic Industry Corporation produced the top three core patents. The top three companies in terms of citations per patent are Hydro-Quebec, Saudi Basic Industry Corporation, and Toray Industries, Inc. (Table 2.2.6). Major institutions prefer independent research and development, and only Hydro-Quebec, Arkema France, and Showa Denko K.K. have conducted collaborative research and development (Figure 2.2.6).

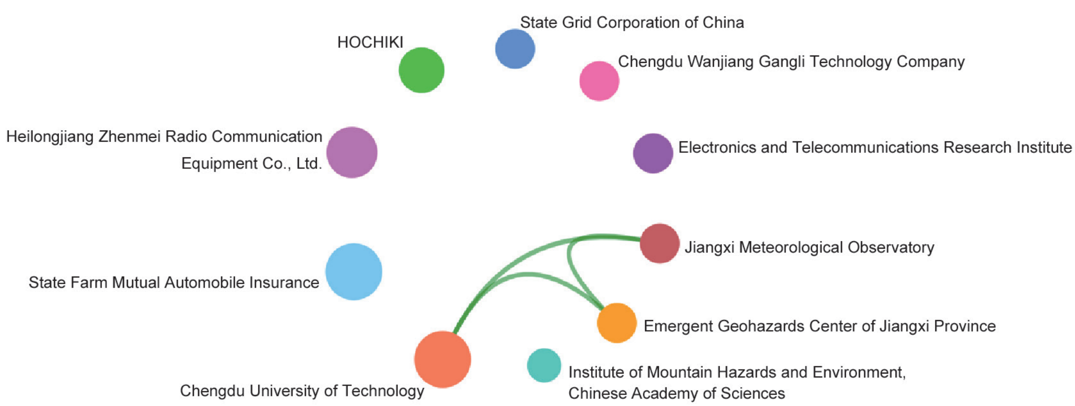

Figure 2.2.4 Collaboration network among major institutions in the engineering development front of “natural disaster prevention, early warning, and restoration decision-making project”

Table 2.2.5 Countries with the greatest output of core patents on “carbon-fiber-based electronic devices”

No.	Country	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	China	323	32.30%	459	3.78%	1.42
2	Japan	261	26.10%	2 368	19.51%	9.07
3	USA	156	15.60%	6 952	57.27%	44.56
4	South Korea	99	9.90%	696	5.73%	7.03
5	Germany	41	4.10%	336	2.77%	8.20
6	France	30	3.00%	223	1.84%	7.43
7	Canada	24	2.40%	309	2.55%	12.88
8	Netherlands	22	2.20%	237	1.95%	10.77
9	Switzerland	16	1.60%	303	2.50%	18.94
10	UK	16	1.60%	267	2.20%	16.69

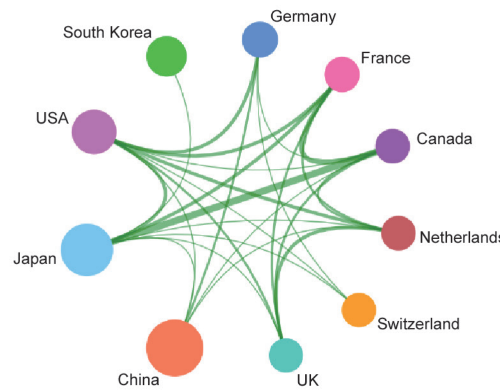

Figure 2.2.5 Collaboration network among major countries in the engineering development front of "carbon-fiber-based electronic devices"

Table 2.2.6 Institutions with the greatest output of core patents on "carbon-fiber-based electronic devices"

No.	Institution	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	LG Chemical Ltd.	36	3.60%	250	2.06%	6.94
2	Toray Industries, Inc.	32	3.20%	556	4.58%	17.38
3	Saudi Basic Industry Corporation	19	1.90%	408	3.36%	21.47
4	Teijin Limited	15	1.50%	151	1.24%	10.07
5	Hydro-Quebec	12	1.20%	270	2.22%	22.50
6	Mitsubishi Chemical Corporation	11	1.10%	80	0.66%	7.27
7	Arkema France	10	1.00%	156	1.29%	15.60
8	Showa Denko K.K.	10	1.00%	101	0.83%	10.10
9	Shin-Etsu Chemical Co., Ltd.	10	1.00%	83	0.68%	8.30
10	Asahi Kasei Corporation	10	1.00%	46	0.38%	4.60

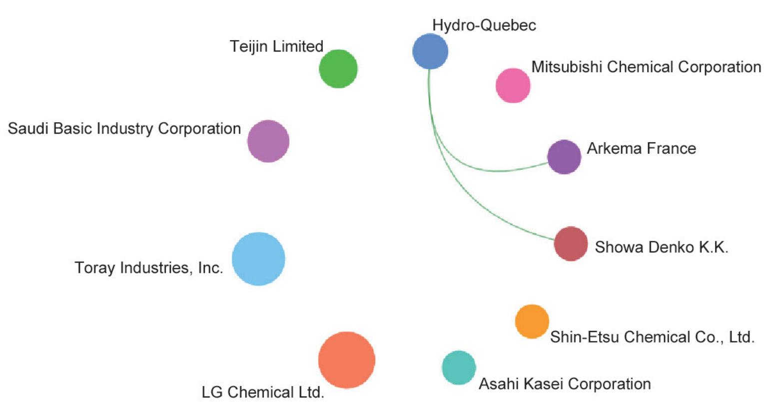

Figure 2.2.6 Collaboration network among major institutions in the engineering development front of "carbon-fiber-based electronic devices"

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