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 include the subfields of environmental science, meteorological science, marine science, food science, textile science, and light industry science. The citation statistics for these research fronts and the annual number of core papers for each research front between 2015 and 2020 are summarized in Tables 1.1.1 and 1.1.2, respectively.

(1) Response mechanism of the soil carbon pool to global climate change

The soil carbon pool refers to the storage of organic matter, litter, and aboveground and underground biomass in the soil ecosystem. It provides sufficient nutrients for all forms of life in the terrestrial ecosystem, exchanges carbon and other resources with ecosystems such as the atmosphere and water, and plays a very important role in the global ecological cycle system. However, in recent years, with the intensification of global climate change, the frequency of climate disasters such as typhoons, floods, droughts, and heat waves has been increasing. This has aggravated the burden and deterioration of the ecological environment, especially the soil carbon pool, which is an important part of the ecological cycle system. In addition, the environmental factors affecting the soil are complex, changeable, and heterogeneous. When the sunlight, temperature, humidity, and other parameters vary because of climate change, the response mechanism of the various environmental factors affecting the soil ecosystem is very important for determining the composition and stability of the soil carbon pool. The soil carbon pool is also the main source of carbon accumulation, which plays a certain role in reducing carbon emissions and improving global climate change. Under the background of global carbon peak and carbon neutrality, clarifying the response mechanism of the soil carbon pool to the global climate change has become a research hotspot and has made good progress. Currently, the focus is on the response process of the carbon pool to climate change in different soil types, such as the grassland ecosystem and farmland soil. However, there are relatively

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	Response mechanism of the soil carbon pool to global climate change	50	3 034	60.68	2018.2
2	Catalysts for low-temperature oxidation of atmospheric volatile organic compounds	113	11 662	103.20	2016.7
3	Technologies for resource and energy recovery from urban sewage	248	20 775	83.77	2016.6
4	Effects of ozone and aerosol complex pollution on human health	7	2 423	346.14	2017.7
5	Compound extreme climate events and disaster risks	1 008	46 867	46.50	2016.8
6	Climate change under the goals of carbon neutrality and carbon peak	1 070	104 283	97.46	2016.7
7	The carbon storage theory of marine microbial carbon pump	22	2 045	92.95	2016.1
8	Preparation and functional application of superwetting biomass-based composite fibers	55	4 681	85.11	2016.7
9	Design of personalized, nutritious and healthy food as well as intelligent catering technology	1 168	12 473	10.68	2017.6
10	Design and development of nanocarbon-based reinforced polymer composites	1 570	111 460	70.99	2017.0

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	2015	2016	2017	2018	2019	2020
1	Response mechanism of the soil carbon pool to global climate change	0	0	10	23	14	3
2	Catalysts for low-temperature oxidation of atmospheric volatile organic compounds	29	28	22	21	10	3
3	Technologies for resource and energy recovery from urban sewage	69	63	48	36	21	11
4	Effects of ozone and aerosol complex pollution on human health	0	0	3	3	1	0
5	Compound extreme climate events and disaster risks	261	240	181	181	95	50
6	Climate change under the goals of carbon neutrality and carbon peak	267	254	224	188	101	36
7	The carbon storage theory of marine microbial carbon pump	7	7	6	2	0	0
8	Preparation and functional application of superwetting biomass-based composite fibers	12	14	11	12	6	0
9	Design of personalized, nutritious and healthy food as well as intelligent catering technology	181	150	210	172	227	228
10	Design and development of nanocarbon-based reinforced polymer composites	322	350	299	327	184	88

few studies on the response processes and mechanisms of different environmental factors affecting the soil to climate change. Similarly, there is a lack of research on a global scale. Therefore, it is of great significance to further analyze the response mechanism of the soil carbon pool to global climate change from the perspectives of macro, large-scale, and micro factors to mitigate the impact of climate change and achieve the goal of carbon neutrality.

(2) Catalysts for low-temperature oxidation of atmospheric volatile organic compounds (VOCs)

VOCs are major atmospheric pollutants and act as important precursors and reactants of combined atmospheric pollution. Thus, controlling VOC pollution is important for improving the quality of the atmospheric environment. Catalytic oxidation is a key technology for the removal of VOCs, and catalysts play a decisive role in its performance. Recently, the desired high-efficiency oxidation of VOCs at low temperatures has demanded catalysts with high performance. Thus, the research on catalysts for low-temperature oxidation of atmospheric VOCs has become one of the frontiers in environmental catalysis. The early studies on this frontier were mostly focused on the oxidation of formaldehyde, and more attention was given to catalysts for the low oxidation of aromatic hydrocarbons such as toluene in the past two years. The investigations into such catalysts are mainly aimed at continuously decreasing the activation energy of VOC oxidation. The active components of such catalysts primarily include noble metals (e.g., Pd, Pt, and Au) and metal oxides. In addition, novel catalysts such as metal–organic frameworks have been investigated. Various principles, including interfacial effects, morphological effects, defect effects, and size effects, have been utilized to improve the performance of catalysts, among which modulating the interaction between the metal and its supporting material is a key strategy. Reportedly, the complete conversion of formaldehyde at room temperature has been realized via the development of catalysts such as Pt/ZrO_2 and Co_3O_4. However, higher temperatures are still required for the complete degradation of aromatic hydrocarbons such as toluene, leaving more room for improving the performance of such catalysts. In addition, halogen- and sulfur-containing compounds, which usually coexist with VOCs, tend to poison the catalysts. Therefore, a rational design to improve the anti-poisoning performance of catalysts is an important future direction for this frontier.

(3) Technologies for resource and energy recovery from urban sewage

The aerobic biological treatment technology represented by the activated sludge process has been playing an active role in urban sewage treatment for a long time. However, the conventional aerobic activated sludge process has some limitations in terms of the process principle, such as high reagent and energy consumption as well as insufficient resource recovery. With the international community's concern on carbon emission reduction and sustainable development, the advancement of efficient resource and energy recovery technologies for urban sewage treatment has become an important research direction in the field of water treatment.

Organic matter, nitrogen, phosphorus, and water are important valuable resources found in sewage. However, these substances are either eliminated or discharged during the sewage treatment process, which leads to a significant waste of resources and contradicts the development strategy of energy conservation, emission reduction, and resource conservation. In this regard, the separation and recovery of these valuable resources is of great significance for sustainable water treatment. The recovery technologies for organic matter include direct anaerobic digestion of sewage, anaerobic fermentation of sludge, and anaerobic membrane bioreactor technology. The recovery technologies for nitrogen and phosphorus include microalgae biomass conversion and struvite nitrogen and phosphorus recovery technologies. In addition, membrane separation is the most important technology for water recycling and resource recovery. The current studies mainly focus on membrane material modification and *in situ* control of membrane fouling. The core idea of these studies is to realize the safe and efficient utilization of valuable resources in sewage and support the sustainable development of urban water circulation systems through fine screening and efficient directional value-added transformation of the useful substances in sewage.

Another focus of research in related fields is energy conservation, emission reduction, and energy recovery during sewage treatment. The related technologies in these aspects include short-cut nitrification, anaerobic ammonia oxidation denitrification, precise aeration, sludge anaerobic digestion biogas production, sludge direct incineration power generation, and sewage source heat pump. Sewage plants can achieve the goal of energy self-sufficiency by reducing the energy consumption of aeration, utilizing the chemical energy in organic matter, and recycling the waste heat of effluents.

The urban sewage treatment system is a complex process under the joint action of multiple factors. It is greatly affected by local natural conditions, sewage quantity, influent and effluent quality, operation and maintenance level, etc. Future research will focus on how to apply sewage resources and energy recovery technologies according to local conditions in the process of sewage treatment.

(4) Effects of ozone and aerosol complex pollution on human health

Pollutants such as nitrogen oxides (NO_x) and VOCs emitted from natural and anthropogenic sources can undergo a series of complex reactions under solar radiation to produce highly oxidizing products such as ozone (O_3), as well as various secondary particulate matter (aerosols). Ozone and aerosol pollution can coexist at high concentrations, forming complex air pollution, which commonly occurs in urban regions in China. Large quantities of ozone and secondary particulate matter can be generated simultaneously in complex air pollution. VOCs and NO_x are precursors for both ozone and secondary particulate matter, and the strong oxidability of the atmosphere is the driving force of the reaction.

Many studies on the health effects of individual exposure to O_3 and aerosols (especially PM2.5) have been conducted. These studies have shown that exposure to O_3 and PM2.5 causes adverse effects on human health, damaging the respiratory system, cardiovascular system, nervous system, immune system, and embryo development, and increasing the risks of cancer, teratogenesis, and mutagenesis. In complex air pollution, the concentrations of O_3 and PM2.5 show a strong positive correlation and exceed the prescribed standard limits. Statistical studies demonstrate that high exposure to O_3 may enhance the effect of PM2.5 on total mortality and respiratory diseases. Similarly, high exposure to PM2.5 may enhance the impact of O_3 on respiratory diseases. However, the extent and mechanism of the interactive effects of O_3 and PM2.5 on human health are still not clear. Therefore, it is necessary to further strengthen the research on the combined impact of ozone and aerosols on human health under complex air pollution to provide scientific support for the coordinated treatment of ozone and aerosols.

(5) Compound extreme climate events and disaster risks

In recent years, a category of extreme events with more catastrophic effects, such as storm surge–heavy precipitation, high temperature–drought, and high temperature–high humidity, has begun to attract people's attention. Compared with traditional extreme weather and climate events defined by the extreme value of a single weather and climate variable, compound events involve two or more climate variables that simultaneously or continuously exceed the extreme thresholds. The combination of these extreme events can greatly intensify their destructiveness; in other words, they are not extremely destructive when they occur separately, but they can cause serious effects when they occur simultaneously. For example, compound events combined with precipitation or extreme warming are extreme events with high disaster risk and impact. The changes in their frequency and intensity in the context of global warming directly affect energy demand, transportation, and crop production, and can easily cause serious economic impact and loss of life. However, the current understanding of the mechanisms and feedback processes of compound extreme events affecting various aspects of social life, such as energy, transportation, construction, agriculture, and tourism, still lacks supporting quantitative and systematic observation and experimental data. More observational and experimental studies are required in the future to improve the understanding of key issues of climate change and the level of disaster risk management.

(6) Climate change under the goals of carbon neutrality and carbon peak

In 2020, General Secretary Xi Jinping solemnly announced to the international community that China would adopt more effective policies and measures to achieve the peak of CO_2 emissions by 2030 and carbon neutrality by 2060. Focusing on the goal of carbon peak and carbon neutrality, it is necessary to strengthen the tracking and analysis of international climate change situations and participate in the formulation of relevant national climate strategies. The significance and impact of national strategies, such as carbon peaking and carbon neutrality, on climate change research should be further studied. It is also necessary to strengthen the research on the impact of climate change on the economic development, industrial structure layout, spatial planning, as well as the multi-circle interaction of the climate system and the abnormal impact process mechanism. Developing and improving technologies, such as climate change detection and attribution, satellite remote sensing monitoring applications, monitoring methods of global greenhouse gases, and multiple climate variables, are required. Moreover, research and development of earth system models, including multi-cycle coupling of the ecological environment and human activities, and high-resolution refined regional climate models, is important. Carrying out quantitative and dynamic disaster risk assessments for key directions such as food security, water resources, ecological environment, sea level, human health, and infrastructure is required. In addition, building a sustainable urbanization development path with climate resilience to ensure climate security and conducting research on climatic and ecological effects of large-scale renewable energy development to effectively improve the level of renewable energy climate services are necessary to achieve the goals of carbon peak and carbon neutrality.

(7) The carbon storage theory of marine microbial carbon pump

The marine microbial carbon pump (MCP) provides a conceptual framework for understanding the role of microbial processes in recalcitrant dissolved organic carbon (RDOC) generation and relevant carbon storage in the ocean. The MCP transforms some organic carbon from reactive dissolved organic carbon (DOC) pools to a recalcitrant carbon reservoir in the form of RDOC, which explains the mechanisms of the large DOC inventory in the ocean. Currently, the main directions of MCP research include analytical methods and molecular characteristics of RDOC, interaction mechanisms between marine microorganisms and DOC, effects of viral and protozoa-mediated carbon cycling on marine organic carbon, characteristics of energy metabolism, and carbon storage efficiency. In the future, the MCP research needs to address the microbial processes of DOC regulation at various taxonomic and functional group levels, as well as the associated community shifts and trophic dynamics. In addition, it is also necessary to explore the metabolism of uptake and intracellular transformation of RDOC in functional microorganisms.

(8) Preparation and functional application of superwetting biomass-based composite fibers

Superwetting materials are emerging products with contact angles larger than 150° (superlyophobic) or smaller than 10° (superlyophilic), which are widely utilized in self-cleaning, oil–water separation, micro-droplet manipulation, anti-fog, anti-icing, and other systems. However, conventional superwetting materials have high production costs, poor biodegradability, and complicated preparation processes. Thus, it is of great significance to develop cost-effective and environmentally friendly superwetting materials.

Biomass, a typical natural polymer, is an abundant renewable resource with low pollution and high safety level. Biomass is rich in reactive functional groups such as hydroxyl, carboxyl, and amino groups, which is beneficial for the precise regulation of material wettability. Therefore, biomass is recognized as an ideal resource for large-scale production of green superwetting materials. Currently, some superwetting biomass-based composite fibers have been successfully developed through the modification of biomasses with unique structures (e.g., cellulose, collagen, and silk protein). However, the practical commercialization of superwetting biomass-based composite fibers is still encountering some challenges. Consequently, it is critically important to investigate the corrosion resistance and long-term stability of superwetting biomass-based composite fibers under extreme conditions, as well as the expansion of functionalities and applications in the future.

(9) Design of personalized nutritious and healthy food as well as intelligent catering technology

The design of personalized nutritious and healthy food as well as smart catering are the bases for providing accurate nutritional support to the people. At present, other developed countries have a relatively high starting point in non-digestive tract targeting technology and high-throughput detection technology. Thus, China should take actions for the advancement of research and development in this field as soon as possible, actively combine the nutrition professional system with emerging cutting-edge technologies, and fully support the country's independent 5G technology, smart sensor technology, and high-throughput multi-protein technology. The technical advantages of chip detection technology, PLC touch screen control technology, and intelligent robot learning and calculation should be utilized. Based on dietary nutrition and human health big data, China should establish dietary intervention models for people of different ages, genetic backgrounds, and health conditions; develop intelligent catering systems and applicable tools that can meet their nutritional and health needs; establish a complete set of food 3D printing technology systems; develop and manufacture food materials with clear nutritional ingredients, excellent texture, and sensory characteristics; design and produce personalized dietary supplements; realize the intelligent manufacturing of personalized nutritional formula foods; and safely and effectively meet consumers' personalized nutrition and health demands.

(10) Design and development of nanocarbon-based reinforced polymer composites

The carbon-based nanoreinforced polymer composite is a new type of material that has emerged in recent years. Carbon-based nanomaterials have the fixed characteristics of carbon materials, high electrical conductivity, tubular structure, and large aspect ratio, as well as the advantages of high specific strength, low density, and high corrosion, temperature, and oxidation resistance. Therefore, carbon-based nanomaterials are ideal fillers for polymer composites.

Compounding carbon-based nanomaterials with polymers can fully exploit the excellent physical and chemical properties of carbon-based nanofibers. It can also harness the advantages of low density, good fluidity, and easy molding of the polymer matrix to obtain carbon-based nanoreinforced polymer composites with special or excellent properties. Nanocarbon-based polymer composites have broad application prospects in information technology materials, biomedical materials, stealth materials, catalysts, high-performance structural materials, multifunctional materials, etc. Currently, the preparation methods for nanocarbon-based reinforced polymer composites mainly include solvent evaporation, solution preparation, chemical grafting, and *in-situ* polymerization. The future research directions mainly focus on the dispersion and phase structure of nanocarbon materials in the polymer matrix, relationship between the structure and properties of composite materials, theoretical prediction of their properties, and new preparation technologies.

1.2 Interpretations for three key engineering research fronts

1.2.1 Response mechanism of the soil carbon pool to global climate change

The soil carbon pool is the largest carbon pool in the global ecosystem and is the link between the atmosphere, rock sphere, and other ecosystems. Therefore, while studying global climate change, the international community is also focusing on the response mechanism of the soil carbon pool to global climate change.

Currently, based on the existing research results and conclusions on the changes in the soil carbon pool, it is possible to predict and evaluate the response changes in the "source" and "sink" of the soil carbon pool in certain conditions under the intensification of human activities such as land cultivation and utilization, agricultural production, and global climate change. However, owing to the heterogeneity, complexity, and variability of soil types, the effects of different regions, types, and environmental factors on the composition of the soil carbon pool may not be consistent. Therefore, the current international research focuses on the response mechanisms and action processes between the climate change and soil carbon pool in different soil types. Moreover, because of the different soil types, their basic physical and chemical properties and environmental factors also differ. Among the factors, the interaction between the soil organic matter and climate change is very important. As one of the main "warehouses" of soil organic carbon, organic matter plays an important role in the global carbon cycle. First, the decomposition of organic matter strengthens the process of soil respiration and releases CO_2 into the atmosphere, leading to global warming. Second, organic matter can adsorb and store organic carbon in soil. In addition to soil organic matter, the composition and activity of various microbial communities in the soil environment are also closely related to the response of the soil carbon pool to climate change. Therefore, the changes in these environmental factors are also key research directions for the international community.

Clarifying the changes in the soil environmental factors, especially organic matter, microbial community, and other indicators, is a prerequisite for exploring the response mechanism of the soil carbon pool to global climate change. Research methods such as micro-, macro-, and global-scale simulation calculations can be adopted. Macro research mainly refers to carrying out plot and field tests to determine the response process and action mechanism of the soil carbon pool to climate change in a specific environment by adjusting the different test parameters, such as temperature, humidity, and organic carbon storage. Micro research mainly involves the analysis and determination of the micro morphology and structure of soil organic carbon by X-ray diffraction, scanning electron microscopy, transmission electron microscopy, and nuclear magnetic resonance spectrometry to analyze the influence of climate change on the soil carbon pool under macro conditions from a micro perspective.

To better predict and evaluate the response mechanism of the soil carbon pool to global climate change, many countries and research institutions have done much work in large-scale model construction.

According to Table 1.2.1, the main contributors of core papers in this research direction are the USA, the UK, Australia, and China. Among them, the USA ranks first, accounting for 50.00%, followed by the UK with 28.00%. The total number of core papers in the UK and the USA accounts for approximately 80% of the total number of global papers.

As indicated in Table 1.2.2, the National Center for Atmospheric Research of China, Cornell University, James Cook University, California Institute of Technology, Pacific Northwest National Laboratory, and University of Cambridge have produced more than four core papers.

According to Figure 1.2.1, the USA, China, Germany, Canada, Australia, and the UK have given more attention to the cooperation in this field. The USA has published the most papers, mainly in collaboration with China and the UK.

According to Figure 1.2.2, the National Center for Atmospheric Research of China, Cornell University, James Cook University, California Institute of Technology, Pacific Northwest National Laboratory, and other institutions have cooperative relations.

Based on Table 1.2.3, the USA has produced the most cited core papers, with a proportion of 25.82%, followed by China with 22.14% and the UK with 10.04%.

As presented in Table 1.2.4, the Chinese Academy of Sciences and the University of Chinese Academy of Sciences have produced the most cited core papers, accounting for 32.79% and 13.73%, respectively.

Based on the output and number of cited core papers on the response mechanism of the soil carbon pool to global climate change, the USA and the UK are both at the forefront of the world, and the number of cited core papers in Chinese research institutions is relatively large.

1.2.2 Compound extreme climate events and disaster risk

In the context of global warming, the frequency and intensity of extreme weather and climate events (e.g., El Niño, drought, floods, thunderstorms, hail, storms, high-temperature weather, and sandstorms) have increased significantly, resulting in serious impacts on society, the economy, and people's lives. In the future, extreme events will become more frequent with increasing atmospheric temperature. In

Table 1.2.1 Countries with the greatest output of core papers on "response mechanism of the soil carbon pool to global climate change"

No.	Country	Core papers	Percentage of core papers	Citations	Citations per paper	Mean year
1	USA	25	50.00%	1 703	68.12	2018.0
2	UK	14	28.00%	780	55.71	2018.6
3	Australia	11	22.00%	1 008	91.64	2018.4
4	China	11	22.00%	589	53.55	2018.1
5	Canada	10	20.00%	512	51.20	2018.4
6	France	7	14.00%	729	104.14	2018.6
7	Germany	6	12.00%	403	67.17	2018.5
8	South Korea	4	8.00%	267	66.75	2018.5
9	Norway	4	8.00%	240	60.00	2018.2
10	Finland	3	6.00%	179	59.67	2018.3

Table 1.2.2 Institutions with the greatest output of core papers on "response mechanism of the soil carbon pool to global climate change"

No.	Institution	Core papers	Percentage of core papers	Citations	Citations per paper	Mean year
1	National Center for Atmospheric Research	6	12.00%	288	48.00	2017.7
2	Cornell University	5	10.00%	261	52.20	2017.2
3	James Cook University	4	8.00%	325	81.25	2018.5
4	California Institute of Technology	4	8.00%	213	53.25	2017.0
5	Pacific Northwest National Laboratory	4	8.00%	213	53.25	2017.0
6	University of Cambridge	4	8.00%	190	47.50	2018.2
7	University of Tasmania	3	6.00%	403	134.33	2018.7
8	University of Technology Sydney	3	6.00%	224	74.67	2018.3
9	The Hong Kong University of Science and Technology	3	6.00%	184	61.33	2019.0
10	Chinese Academy of Sciences	3	6.00%	178	59.33	2017.3

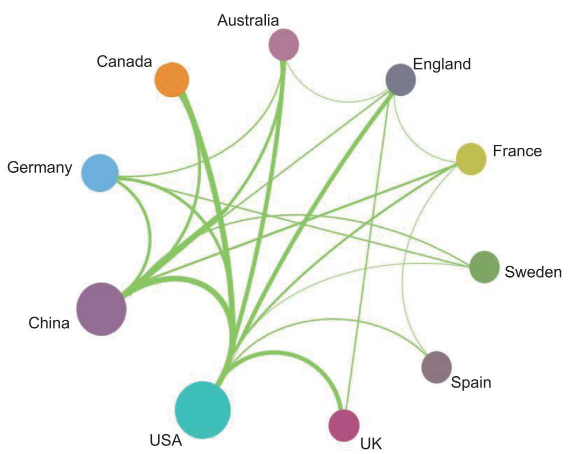

Figure 1.2.1 Collaboration network among major countries in the engineering research front of "response mechanism of the soil carbon pool to global climate change"

addition to regular changes such as heavy precipitation, high temperature, and heat waves, the probability of compound extreme events will also increase. In recent years, extreme sea level events characterized by storm surges, huge ocean waves, and tidal floods have occurred frequently in coastal areas. These extreme oceanic events, including heavy rainfall and strong typhoon events, will become more common.

The countries with the greatest output of core papers on "compound extreme climate events and disaster risk" are listed in Table 1.2.5. The USA ranks first in the number of core papers, followed by China and the United Kingdom. The same ranking can be observed in the frequency of citations. Other countries have a large gap compared with the USA, which indicates that it has great research advantages in this aspect.

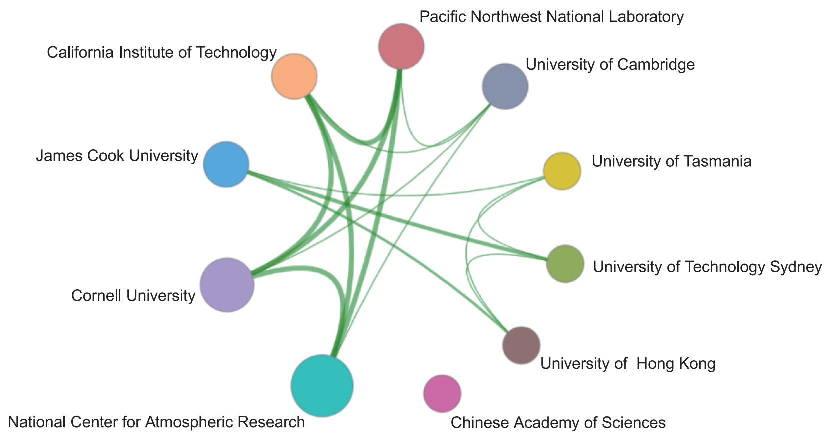

Figure 1.2.2 Collaboration network among major institutions in the engineering research front of “response mechanism of the soil carbon pool to global climate change”

Table 1.2.3 Countries with the greatest output of citing papers on “response mechanism of the soil carbon pool to global climate change”

No.	Country	Citing papers	Percentage of citing papers	Mean year
1	USA	3 185	25.82%	2018.9
2	China	2 731	22.14%	2019.2
3	UK	1 239	10.04%	2018.9
4	Germany	1 049	8.50%	2018.9
5	Australia	754	6.11%	2019.1
6	France	729	5.91%	2018.9
7	Canada	695	5.63%	2019.0
8	Italy	560	4.54%	2018.9
9	Spain	554	4.49%	2019.0
10	Switzerland	452	3.66%	2018.9

Table 1.2.4 Institutions with the greatest output of citing papers on “response mechanism of the soil carbon pool to global climate change”

No.	Institution	Citing papers	Percentage of citing papers	Mean year
1	Chinese Academy of Sciences	970	32.79%	2019.1
2	University of Chinese Academy of Sciences	406	13.73%	2019.2
3	National Center for Atmospheric Research	213	7.20%	2019.0
4	Nanjing University of Information Science & Technology	212	7.17%	2019.0
5	Columbia University	206	6.96%	2018.9
6	National Oceanic and Atmospheric Administration	172	5.81%	2018.7
7	ETH Zurich	168	5.68%	2018.9
8	Beijing Normal University	163	5.51%	2018.8
9	University of Washington	158	5.34%	2018.8
10	University of Colorado	151	5.10%	2018.7

In the citations per paper, China has a relatively small number. Canada ranks first, although its number of core papers ranks tenth, illustrating the importance of publishing high-level core papers recognized by peers. In terms of cooperation networks of the major contributing countries (Figure 1.2.3), each country has shown extensive cooperation with the USA and followed by the UK and China.

Table 1.2.6 displays the organizations with major outputs for core papers in this engineering research front. The institution that has published the most number of core papers is the Chinese Academy of Sciences. According to the main inter-agency cooperation network (Figure 1.2.4), the Chinese Academy of Sciences has worked in cooperation with other major institutions, including Columbia University, Harvard University, and the University of Tokyo. Moreover, the cooperation among the 10 institutions has been very close.

For the countries that have cited core papers, China ranks second, and a certain gap from the USA, which ranks first, still exists (Table 1.2.7). The Chinese Academy of Sciences ranks first among the institutions that have cited core papers, followed by Columbia University and University of Washington (Table 1.2.8). It can be seen that the USA is ahead worldwide in the study of "compound extreme climate events and disaster risk" and has worked in close cooperation with other countries. The Chinese Academy of Sciences is leading among the research institutions in this field and should continue to maintain a relevant research focus on this front.

1.2.3 Preparation and functional application of superwetting biomass-based composite fibers

Superwettability is a widespread phenomenon found in nature, which refers to the extreme wetting properties of solid materials, including superlyophobicity and superlyophilicity. Common superhydrophobic materials with contact angles larger than 150° include superhydrophobic materials, superoleophobic materials, and superamphiphobic materials. In contrast, superlyophilic materials refer to those with contact angles smaller than 10°, such as superhydrophilic materials and superoleophilic materials. Based on the special functionalities on the surface and interface, superwetting materials play a significant role in self-cleaning, oil–water separation, micro-droplet manipulation, anti-fog, and anti-icing systems. Although conventional superwetting materials have achieved certain positive effects in practical applications, they also have the disadvantages of high production cost, poor biodegradability, and complicated preparation process. Along with the advancement of technologies and the improvement of material performance requirements, numerous new materials have been employed in manufacturing such materials. This has promoted the rapid development of cost-effective and environmentally friendly superwetting materials.

Biomass refers to various materials produced through photosynthesis, including plants, animals, microorganisms, and their derived wastes. Biomass is superior because of its abundance, renewability, low pollution, and high level of safety. Moreover, as a typical natural polymer, biomass is rich in reactive functional groups such as hydroxyl, carboxyl, and amino groups, which can further regulate its surface wettability. With the above merits, biomass can be used for large-scale production of green superwetting materials. Currently, some investigators have successfully fabricated biomass-based composite superwetting materials by controlling the structure and chemical properties of biomass through a series of physical and chemical methods. Biomasses featuring unique structures (e.g., collagen, silk protein, and cellulose) have been exploited as high-performance superwetting biomass-based composite fibers by controlling the design and preparation, such as introducing special structures and regulating the surface energy.

Superwetting biomass-based composite fibers can be processed into various forms, including aerogels, membrane materials, and powdered fillers, which are extensively utilized in oil–water separation, biosensing, and microfluidics. However, superwetting biomass-based composite fibers are still facing many challenges in practical applications, such as the limitations in corrosion resistance and long-term stability, as well as the difficulty in maintaining a long service life in harsh environments. It is necessary to thoroughly investigate and optimize the fabrication of superwetting biomass-based composite fibers, as well as expand the scope of their functional applications.

Through the analysis of core papers on "preparation and functional application of superwetting biomass-based composite fibers", it was found that the number of citations per paper is as high as 85.11 times (Table 1.1.1). Table 1.2.9 displays the countries with the greatest output of core papers in this research front. Among them, China ranks first with a

Table 1.2.5 Countries with the greatest output of core papers on “compound extreme climate events and disaster risk”

No.	Country	Core papers	Percentage of core papers	Citations	Percentage of citations	Mean year
1	USA	328	32.54%	16 905	51.54	2016.8
2	China	210	20.83%	9 989	47.57	2017.1
3	UK	158	15.67%	8 967	56.75	2016.8
4	Australia	100	9.92%	6 045	60.45	2016.8
5	Germany	90	8.93%	5 387	59.86	2016.9
6	Italy	89	8.83%	5 090	57.19	2017.1
7	Netherlands	84	8.33%	5 116	60.90	2017.0
8	Japan	78	7.74%	3 910	50.13	2016.2
9	Switzerland	52	5.16%	3 525	67.79	2017.1
10	Canada	47	4.66%	3 542	75.36	2017.0

Table 1.2.6 Institutions with the greatest output of core papers on “compound extreme climate events and disaster risk”

No.	Institution	Core papers	Percentage of core papers	Citations	Percentage of citations	Mean year
1	Chinese Academy of Sciences	42	4.17%	2 113	50.31	2016.6
2	Vrije University Amsterdam	30	2.98%	2 070	69.00	2016.8
3	Columbia University	28	2.78%	1 727	61.68	2016.8
4	Harvard University	23	2.28%	1 888	82.09	2017.3
5	The University of Tokyo	23	2.28%	1 672	72.70	2016.2
6	Beijing Normal University	22	2.18%	1 171	53.23	2016.7
7	University College London	19	1.88%	1 369	72.05	2016.2
8	University of Colorado	17	1.69%	962	56.59	2016.3
9	European Commiss	17	1.69%	900	52.94	2017.5
10	Swiss Federal Institute of Technology in Zurich	16	1.59%	1 557	97.31	2017.1

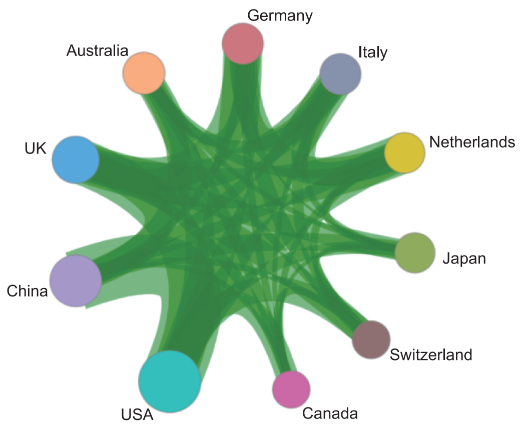

Figure 1.2.3 Collaboration network among major countries in the engineering research front of “compound extreme climate events and disaster risk”

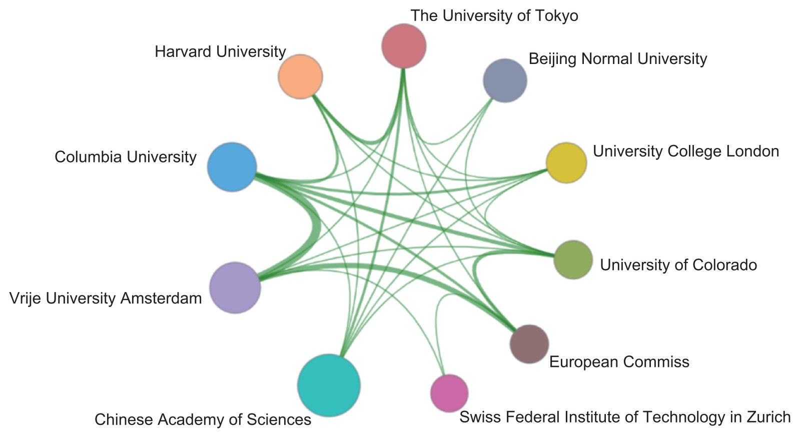

Figure 1.2.4 Collaboration network among major institutions in the engineering research front of “compound extreme climate events and disaster risk”

Table 1.2.7 Countries with the greatest output of citing papers on “compound extreme climate events and disaster risk”

No.	Country	Citing papers	Percentage of citing papers	Mean year
1	USA	1 068	23.00%	2017.9
2	China	884	19.04%	2018.1
3	UK	547	11.78%	2017.9
4	Australia	375	8.08%	2018.1
5	Germany	367	7.90%	2017.9
6	Italy	282	6.07%	2017.8
7	Netherlands	282	6.07%	2017.9
8	France	234	5.04%	2017.9
9	Canada	211	4.54%	2018.2
10	Iran	202	4.35%	2018.3

Table 1.2.8 Institutions with the greatest output of citing papers on “compound extreme climate events and disaster risk”

No.	Country	Country	Citing papers	Percentage of citing papers	Mean year
1	Chinese Academy of Sciences	China	159	18.71%	2018.0
2	Columbia University	USA	89	10.47%	2018.1
3	University of Washington	USA	83	9.76%	2018.2
4	Harvard University	USA	78	9.18%	2017.9
5	University of Oxford	UK	76	8.94%	2018.2
6	Duy Tan University	Vietnam	71	8.35%	2018.9
7	The university of Melbourne	Australia	63	7.41%	2018.2
8	Stanford University	USA	60	7.06%	2017.9
9	Vrije University Amsterdam	Netherlands	59	6.94%	2017.5
10	Swiss Federal Institute of Technology in Zurich	Switzerland	57	6.71%	2017.8

core paper output of 65.45% and citations of 3 135 times, which indicates that many Chinese experts and scholars are committed to this research front. However, the citations per paper in China lag behind those of Spain, the USA, and Turkey. In terms of the cooperation network of the countries with high outputs (Figure 1.2.5), China has the closest cooperation with the USA. Many countries have also cooperated extensively, while Germany has displayed strong independent research and development capabilities in this field.

As presented in Table 1.2.10, seven of the top ten research institutions are from China: the Chinese Academy of Sciences, Soochow University, Jiangsu University, Sichuan University, Henan Normal University, South China University of Technology, and Zhengzhou University. This further indicates that Chinese researchers are highly enthusiastic on this research front. Among the institutions, the top three in terms of citations per paper are Henan Normal University, South China University of Technology, and Chinese Academy of Sciences. According to the main inter-agency cooperation network (Figure 1.2.6), most of the institutions have worked with other institutions, and a small number have relied mainly on independent research and development.

As for the ranking of cited papers in this research front, China still occupies the leading position worldwide (Table 1.2.11). In addition, the number of cited papers from research institutions in various countries is basically the same (Table 1.2.12).

Table 1.2.9 Countries with the greatest output of core papers on "preparation and functional application of superwetting biomass-based composite fibers"

No.	Country	Core papers	Percentage of core papers	Citations	Citations per paper	Mean year
1	China	36	65.45%	3 135	87.08	2016.9
2	USA	8	14.55%	768	96.00	2017.2
3	India	5	9.09%	382	76.40	2016.8
4	Turkey	3	5.45%	274	91.33	2016.7
5	Singapore	3	5.45%	249	83.00	2017.3
6	Canada	3	5.45%	243	81.00	2017.0
7	Sweden	3	5.45%	229	76.33	2016.3
8	Spain	2	3.64%	214	107.00	2017.5
9	Egypt	2	3.64%	165	82.50	2018.0
10	Germany	2	3.64%	150	75.00	2015.5

Table 1.2.10 Institutions with the greatest output of core papers on "preparation and functional application of superwetting biomass-based composite fibers"

No.	Institution	Country	Core papers	Percentage of core papers	Citations	Citations per paper	Mean year
1	Chinese Academy of Sciences	China	4	7.27%	439	109.75	2016.5
2	Soochow University	China	4	7.27%	335	83.75	2017.2
3	Jiangsu University	China	4	7.27%	303	75.75	2017.2
4	University of Wisconsin	USA	3	5.45%	253	84.33	2016.3
5	Nanyang Technological University	Singapore	3	5.45%	249	83.00	2017.3
6	Sichuan University	China	3	5.45%	190	63.33	2016.3
7	Henan Normal University	China	2	3.64%	278	139.00	2015.5
8	South China University of Technology	China	2	3.64%	226	113.00	2018.5
9	University of Tennessee	USA	2	3.64%	207	103.50	2019.0
10	Zhengzhou University	China	2	3.64%	207	103.50	2019.0

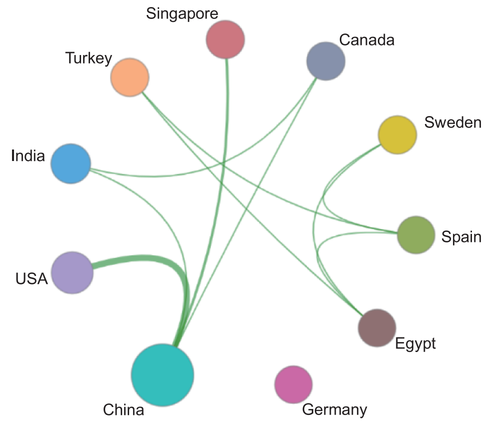

Figure 1.2.5 Collaboration network among major countries in the engineering research front of “preparation and functional application of superwetting biomass-based composite fibers”

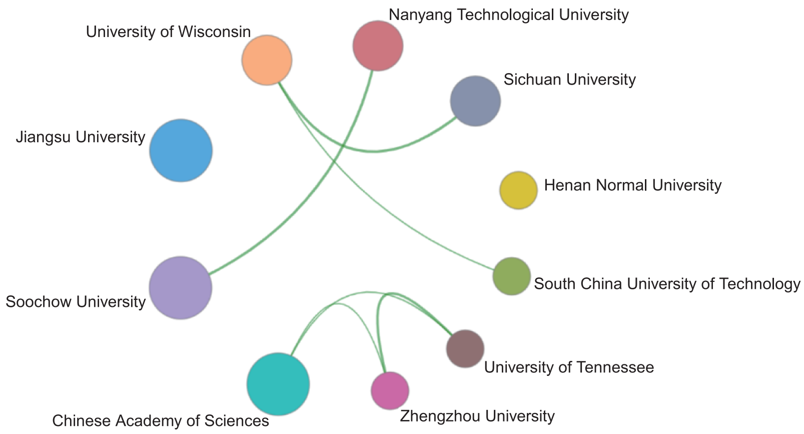

Figure 1.2.6 Collaboration network among major institutions in the engineering research front of “preparation and functional application of superwetting biomass-based composite fibers”

Overall, China is not only ahead of other countries but also has close cooperation with many countries in the engineering research front on “preparation and functional application of superwetting biomass-based composite fibers”. It is recommended that Chinese research institutions should continue to carry out in-depth studies on related fields to maintain the status of this research front and promote the technological development of related industries worldwide.

2 Engineering development fronts

2.1 Trends in the Top 10 engineering development fronts

The Top 10 engineering development fronts in the field of environmental and light textile engineering are summarized in Table 2.1.1. These include the subfields of environmental science, meteorological science, marine science, food science, textile science, and light industry science. The number of patents related to these individual topics between 2015 and 2020 is presented in Table 2.1.2.

(1) Atmospheric oxidation capacity and ozone pollution control

Atmospheric oxidation capacity refers to the capability of the atmosphere to remove pollutants through oxidation reactions. The increased ozone concentration increases the atmospheric oxidation and intensifies the generation of secondary particulate pollutants, thereby aggravating air pollution. Atmospheric compound pollution is widespread in

Table 1.2.11 Countries with the greatest output of citing papers on "preparation and functional application of superwetting biomass-based composite fibers"

No.	Country	Citing papers	Percentage of citing papers	Mean year
1	China	4	26.67%	2017.8
2	Switzerland	2	13.33%	2016.5
3	India	1	6.67%	2017.0
4	Japan	1	6.67%	2017.0
5	UK	1	6.67%	2017.0
6	Singapore	1	6.67%	2017.0
7	Belgium	1	6.67%	2019.0
8	Mexico	1	6.67%	2017.0
9	Spain	1	6.67%	2017.0
10	Germany	1	6.67%	2018.0

Table 1.2.12 Institutions with the greatest output of citing papers on "preparation and functional application of superwetting biomass-based composite fibers"

No.	Institution	Country	Citing papers	Percentage of citing papers	Mean year
1	Indian Institute of Technology Kanpur	India	1	9.09%	2017.0
2	National Institute of Advanced Industrial Science and Technology	Japan	1	9.09%	2017.0
3	University of Sheffield	UK	1	9.09%	2017.0
4	Nanyang Technological University	Singapore	1	9.09%	2017.0
5	Soochow University	China	1	9.09%	2017.0
6	Northwest Normal University	China	1	9.09%	2016.0
7	Nanjing Forestry University	China	1	9.09%	2019.0
8	University of Ghent	Belgium	1	9.09%	2019.0
9	Xi'an Jiaotong University	China	1	9.09%	2019.0

urban agglomerations in China. Strong oxidation is the driving force for the formation of atmospheric compound pollution. Ozone and secondary PM2.5 are generated in the process of atmospheric compound pollution. Therefore, effective control and prevention of ozone and secondary pollution require synergetic control measures based on atmospheric oxidative regulation.

To prevent and control ozone pollution based on atmospheric oxidative regulation, it is necessary to accurately and quantitatively analyze the sources of ozone at different spatial scales, such as city–region–country. Moreover, implementing regional joint prevention and control, clarifying the complicated meteorological process and transmission process of pollutants, and formulating reasonable and effective precursor control strategies should be conducted. In addition, it is necessary to promote research on the secondary formation process and mechanism of ozone pollution in typical areas and systematically explore the temporal–spatial distribution, main controlling factors, and influencing factors of ozone. Scientific support for the identification of regional transmission channels and sensitive areas and the dynamic regulation of precursor emission mitigation also need to be enhanced.

(2) Environmental risk prevention and control technology for CO_2 geological storage

The emergence, development, and implementation of CO_2 capture, utilization, and storage technologies are expected to reduce the amount of greenhouse gases entering the

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

No.	Engineering development front	Published patents	Citations	Citation per patent	Mean year
1	Atmospheric oxidation capacity and ozone pollution control	1 000	5 956	5.96	2017.6
2	Environmental risk prevention and control technology for CO_2 geological storage	1 000	21 153	21.15	2014.2
3	Next-generation sewage treatment plants with enhanced resources and energy recovery	1 000	3 535	3.54	2017.2
4	Deep emission-reduction technology of cross-medium composite pollution under the background of carbon neutrality	252	1 849	7.34	2013.7
5	Marine bionic antifouling technology	1 000	4 296	4.30	2016.5
6	Development of ecological model for carbon neutrality	1 000	46 968	46.97	2012.1
7	Interfacial solar seawater desalination technology	422	4 294	10.18	2016.0
8	Development of new functional natural cellulose fibers	1 000	1 952	1.95	2020.0
9	Food microbial community regulation technology	1 000	6 916	6.92	2010.5
10	Development of environmentally friendly plastic packaging materials and products	1 000	2 306	2.31	2017.5

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	2015	2016	2017	2018	2019	2020
1	Atmospheric oxidation capacity and ozone pollution control	66	88	123	165	187	267
2	Environmental risk prevention and control technology for CO_2 geological storage	127	111	79	83	72	15
3	Next-generation sewage treatment plants with enhanced resources and energy recovery	121	120	147	183	162	170
4	Deep emission-reduction technology of cross-medium composite pollution under the background of carbon neutrality	10	15	20	17	15	24
5	Marine bionic antifouling technology	171	159	161	151	126	115
6	Development of ecological model for carbon neutrality	35	57	56	83	79	80
7	Interfacial solar seawater desalination technology	41	39	49	45	58	57
8	Development of new functional natural cellulose fibers	0	80	0	0	0	626
9	Food microbial community regulation technology	34	73	55	50	46	52
10	Development of environmentally friendly plastic packaging materials and products	46	143	200	268	233	68

atmosphere. CO_2 storage is used worldwide, and storage methods can be broadly divided into natural and artificial modes. Natural modes include terrestrial sequestration, whereas anthropogenic storage includes storage in geological formations. Several modes of utilizing and storing CO_2 include terrestrial sequestration, marine sequestration, and geological storage. Among these, geological storage is the most widely used technology, in which CO_2 is stored in subsurface geological structures such as saline aquifers, depleted oil and gas reservoirs, and unrecoverable coal seams. The storage capacity, holding capacity, and injection capacity of CO_2 depend on the geological and petrophysical properties of the target strata. The most important aspect in implementing CO_2 geological storage projects is to ensure effectiveness, safety, and durability of the burial. CO_2 leakage affects the safety of the population and ecological environment, leads to groundwater pollution, ground deformation, and even induce earthquakes. To reduce the environmental impact on human health, soil vegetation, and groundwater caused by leakage from CO_2 geological storage, it is necessary to perform environmental risk evaluation and prevention and control research of CO_2 geological storage.

The most important environmental risk of CO_2 geological storage is leakage caused by overpressure in aquifers, abandoned wells, faults, and fractures. Most modeling and monitoring studies conducted during the development, implementation, and monitoring phases of CO_2 storage are primarily aimed at avoiding gas leakage into the atmosphere, groundwater aquifers, shallow soil zones, and overlying resource layers, and ensuring safe sequestration of the gas. CO_2 storage projects require accurate siting, characterization (storage capacity estimation and plume modeling), and monitoring to avoid the environmental risk of leakage. Measurement, monitoring, modeling, and validation must be conducted to counter the environmental risks of such projects. Monitoring leaks due to movement of the plume during the post-injection phase of CO_2 storage is essential to detect leaks early and thus ensure that the environment and groundwater are not threatened by the released gas. By monitoring the pressure accumulation in the formation, simulation prediction and validation of leak risk can be achieved. Mass balance verification is also an important aspect of environmental leak risk prevention. This is performed by tracking the amount of injected CO_2 to ensure that it is stored in defined areas and in compliance with the emission quotas set before the start of such projects. Monitoring of CO_2 can be conducted on a spatial or temporal basis. On a spatial basis, CO_2 is monitored according to the area that it affects. This category includes atmospheric monitoring, near-surface monitoring, and subsurface monitoring (involving faults, wells, reservoirs, and seals). On a temporal basis, monitoring can be divided into injection and post-injection phases.

(3) Next-generation sewage treatment plants with enhanced resources and energy recovery

Municipal sewage treatment is an energy-intensive industry in China. To date, more than 3 500 urban sewage treatment plants have been built in China, with an annual power consumption of more than 10 billion kWh. This accounts for over 2% of the total energy consumption in the country, and the proportion is continually increasing. With the continuous promotion of China's carbon emission reduction and sustainable development policies, the goal of sewage treatment plants is also changing from simply removing the water pollutants to sustainable sewage treatment.

Sewage water is one of the most valuable resources. Sewage, after recycling treatment, can provide a large amount of reclaimed water to compensate for the shortage of urban water resources. As early as the 1960s, the USA had put forward the concept of the "21st Century Water Plant" and realized direct drinking reuse after sewage treatment in some areas. In Singapore, the concept of "NEWater" is proposed, which takes the sewage treatment plant as a pretreatment unit for a water reclamation plant and realizes the recycling of domestic sewage.

The recovery of energy and nutrients from sewage is another key target for next-generation sewage plants. The organic matter in sewage is an energy carrier, which can be used to compensate for the operation energy consumption after transformation and enrichment. Moreover, the heat contained in the sewage itself can also be used to supply a large amount of heat/cold energy to the outside by technologies such as water source heat pumps, thereby realizing an energy-neutral sewage treatment process. In the treatment process, the nutrients (mainly phosphorus) in sewage can be effectively recovered, thus delaying the shortage of phosphorus resources to the greatest extent. Regarding the design of sustainable sewage treatment plants, the Netherlands proposed the concept of "NEWs" in 2008, which advocated that the output of the next-generation sewage treatment plant should be threefold: nutrients, energy, and reclaimed water.

Currently, the new generation of sewage treatment plants in China, represented by the "Concept Wastewater Treatment Plants", is attempting to achieve the overall goal of recycling energy, water resources, and nutrients while realizing the basic functions of sewage treatment by exploring technologies such as sewage heat utilization, sludge biogas power generation, and short-cut nitrogen and phosphorus removal. In this process, in addition to the development of relevant water treatment technologies, establishing and improving the sustainable development standard system of the municipal sewage treatment industry and increasing the market acceptance of sewage resources should be the key concerns in the future.

(4) Deep emission reduction technology of cross-medium composite pollution under the background of carbon neutrality

Dealing with climate change is a common concern of humanity. *The Paris Agreement* reached a consensus on the goal of controlling global temperature rise below 2 °C and striving to control it below 1.5 °C. To achieve this goal, all countries must strengthen the control and emission reduction of greenhouse gases. By 2050, the world will achieve nearly zero carbon dioxide emissions or even net zero emissions. In the context of carbon neutrality, pollution prevention and control should not be limited to treatment or reduction but must take low-carbon transformation as the goal, comprehensively consider the deep emission reduction path and technical support of pollutants across media, and build an engineered system.

To achieve this goal, revolutionary technological breakthroughs are required. In addition to further strengthening the generally targeted demand-side management and energy efficiency technologies as well as new energy and renewable energy development technologies, special attention needs to be given to strategic technologies that are not mature and costly, but can play a key role in deep decarbonization. We need to integrate and innovate in terms of information technology, new materials, high-end equipment, and other industries; support each other; comprehensively promote the transformation of the entire industrial chain in various industrial fields dominated by energy; and realize deep emission reduction of pollutants from the source.

(5) Marine bionic antifouling technology

Bionic antifouling technology is a new, non-toxic, bionic antifouling coating and method that take advantage of bionic principles and chemical ecology. It is the most active type of an environment-friendly antifouling coating in recent years. It can replace the conventional antifouling coating (which is harmful to the environment) and has a very broad development prospect.

The main technical directions of bionic antifouling technology include ① finding and using suitable biological antifouling agents to prevent fouling organisms from adhering, without damaging the environment and other non-target organisms;② mimicking biological features with antifouling capabilities by designing special surface and body material characteristics; ③ reducing surface adhesion of the soaked material as much as possible to avoid biological fouling; and ④ preventing marine fouling.

Second, the frontier direction also includes selecting appropriate organisms as biological models and adopting appropriate research methods to explore the correlation factors associated with biological fouling problems in biological models, specific environments, and service modes according to the environment and service forms of marine engineering equipment. In addition, using chemical ecology methods to find natural antifouling agents or develop new antifouling materials is also the research focus of bionic antifouling technology in the future. Furthermore, strengthening the combination and transformation of basic research and applied research by promoting the application and cooperation of chemistry, biology, ecology, environmental science, and other disciplines in the study of marine fouling organisms is an important direction of bionic antifouling technology in the future.

(6) Development of an ecological model for carbon neutrality

For terrestrial ecosystems, the carbon balance capacity is the ability of the ecosystem to absorb and fix carbon in the atmosphere, that is, net ecosystem productivity (NEP), which refers to the remaining part of net primary productivity (NPP) minus the photosynthetic products used by heterotrophic consumption (soil respiration). The NEP can be used to measure the net carbon flux between the ecosystem and the atmosphere. Its expression is NEP = (GPP − Ra) − Rh = NPP − Rh, where GPP is the gross primary productivity, Ra is the autotrophic respiration and Rh is the respiration consumption of heterotrophic organisms (soil respiration). NEP represents the net carbon storage at the ecosystem scale, which can be positive or negative. When NEP is greater than zero, it means that the ecosystem is a CO_2 sink, and the ecosystem absorbs carbon from the atmosphere; otherwise, it is the source, and the ecosystem emits carbon into the atmosphere.

As an example, the biogeochemical model CEVSA is based on the process of plant photosynthesis, respiration, and soil microbial activities to simulate the energy conversion between vegetation, soil, and atmosphere, as well as the water/carbon/nitrogen cycle changes. The model realizes the coupling of multiscale processes in physiological processes (such as stomatal conduction, photosynthesis, respiration, and transpiration), plants (the balanced absorption of light, water, carbon, and nitrogen; the distribution of carbon and nitrogen between the roots, stems, and leaves; and the primary productivity), and ecosystems (the interaction of water, carbon, and nitrogen cycles in the vegetation–soil–atmospheric system and its impact on the NEP) to simulate the dynamic response of ecosystems to environmental changes. The ecological model can be derived by observation data, climate model predictions, and climate change projections. The outputs include NPP, NEP, LAI (leaf area index), soil C, and vegetation C. These are used to simulate, monitor, evaluate, and predict carbon changes in the ecosystem, which can provide basic data for carbon emissions and support the goal of carbon neutrality.

(7) Interfacial solar seawater desalination technology

Interfacial solar seawater desalination is a new photothermal conversion mechanism. Through material design and effective optical and thermal regulation, solar energy is fully absorbed and energy localization is applied to the gas–liquid interface to effectively improve the efficiency of photothermal energy conversion. Interfacial solar seawater desalination has the advantages of simple material preparation, compact structure, and obvious system innovation, which result in efficiency improvement and cost reduction. It is especially suitable for the preparation of fresh water for households in remote mountainous areas and island areas where electricity is lacking.

Photothermal conversion materials are a key factor affecting the evaporation performance of solar-driven interface evaporation systems. Based on different photothermal conversion materials, the main technical directions of interfacial solar seawater desalination technology include carbon-based material photothermal evaporation, metal plasma material photothermal evaporation, and composite material photothermal evaporation systems. Among the available materials, carbon is abundant, inexpensive, and environmentally friendly, and carbon-based nanoparticles have good broadband solar absorbance and efficient light-to-heat conversion efficiency. Carbon materials have been widely used in interfacial solar desalination technology as inexpensive light-absorbing materials.

At present, photothermal materials have achieved efficient light absorption in structural design. However, the following obstacles still need to be overcome in their actual solar evaporation and solar distillation: ① the long-term efficacy of many photothermal materials in treating actual seawater has not been confirmed; ② the existing research often focuses only on the optimization of photothermal materials and evaporation systems but ignores the research on collection systems; ③ the incident angle of sunlight changes constantly every day, and the high-efficiency operation of the actual system outdoors is facing a great challenge; and ④ in the laboratory stage, the system is relatively small, and large-scale production is still facing a severe test. At present, many researchers have begun the research and development of technologies that ensure efficient condensation and collection of steam and recovery and utilization of its latent heat. In the future, the application scope of the interface solar desalination technology will continue to expand.

(8) Development of new functional natural cellulose fibers

With the continuous development of textile science and technology and the concept of green, environmental protection, and ecology, people are requiring textiles with increasingly higher performance. Natural cellulose fibers have attracted increasing attention because of their excellent performance. They are natural fibers with cellulose as their main component, which comes from plants; therefore, they also called plant fibers. They have good environmental compatibility, and their development and application are of great significance for resource utilization and environmental protection.

Functional textiles refer to products that have other special functions (besides providing warmth, covering, and beautifying) beyond conventional textile products. According to their function, textiles can be divided into comfort type, medical health care type, ecological type, protection type, and intelligent functional textile products. In recent years, high value-added functional natural cellulose fiber textile products have achieved very rapid development, and their functionality is constantly changing. The development of new functional natural cellulose fiber textile products integrating ecological environmental protection, multifunctional composites, intelligence, humanization, individuation, and health is bound to have considerable development prospects.

(9) Food microbial community regulation technology

Food microbial community regulation technology is aimed at traditional fermented foods such as vinegar, soy sauce, and baijiu. It comprehensively adopts omics technologies to analyze the microbial composition of the fermentation process and the metabolic network of its main flavoring substances; clarify the main driving factors for the succession of the microbial community; identify the main functional microorganisms succession mechanism; analyze the dynamic changes in the main flavoring substance metabolism network and its influencing factors, focusing on the analysis of the metabolic network changes of the main functional microorganisms under the action of driving factors and their effects on the fermentation process and product flavor; and thoroughly analyze the metabolic characteristics of functional microorganisms. Based on optimization, the core fermentation microbial flora is reconstructed by optimal functional microorganisms. Then, the driving factors are used to develop innovative key fermentation control technologies for the main flavoring substances. Finally, the microbial metabolism can be controlled by adjusting the fermentation process, thereby regulating the flavor quality of the product. Multi-dimensional purebred microbial liquid fermentation technology needs to be developed to improve fermentation efficiency and product quality.

(10) Development of environmentally friendly plastic packaging materials and products

Plastic packaging materials and products are one of the main sources of waste plastic pollutants, which pose potential threats to human health and the natural environment owing to their degradation difficulty under natural conditions. From the perspective of manufacturing, developing environmentally friendly plastics with green, low-carbon, and degradable properties to serve as plastic packaging materials and products is an important breakthrough to solve the pollution issue of waste plastic products. Environmentally friendly plastics are also a new development trend in the packaging industry.

According to their degradation mechanism, environmentally friendly plastics can be classified into three categories: photodegradable, biodegradable, and composite degradable. Photodegradable plastics realize photodegradation under natural ultraviolet radiation by adding photosensitizers to plastics or introducing photosensitive genes into the plastic molecular chains. Biodegradable plastics can be decomposed into harmless substances such as water and carbon dioxide under the action of microorganisms. Composite degradable plastics exhibit both photodegradable and biodegradable properties. Packaging materials and products based on environmentally friendly plastics have been successfully applied to packaging applications for food, decorations, and building materials. However, environmentally friendly plastic packaging materials and products still have the disadvantages of high cost, low mechanical strength, and poor degradation controllability. Therefore, further optimization of environmentally friendly plastic packaging materials and products is essential for technology promotion in the future.

2.2 Interpretations for three key engineering development fronts

2.2.1 Atmospheric oxidation capacity and ozone pollution control

Based on the air pollution prevention and control programs promoted in recent years, China's primary pollutant emissions and primary PM2.5 concentration have been significantly controlled, but ozone and secondary PM2.5 have increased. Among the air pollutants, NOx has remained at the same concentration, whereas the ozone concentration has significantly increased by 21%. Meanwhile, the number of cities with excessive ozone concentrations has increased sharply. In 2019, among the 337 cities, 30.6% exceeded the ozone concentration standard.

As one of the important factors causing regional air pollution, secondary pollutant tropospheric ozone originates from the photochemical reaction of VOCs and NO_x under sunlight. Atmospheric oxidation capacity refers to the ability of the atmosphere to remove pollutants through oxidation reactions. The increase in ozone concentration leads to increased atmospheric oxidation and intensifies the generation of secondary particulate contaminants, thereby aggravating air pollution. Tropospheric ozone, especially near-ground ozone, exceeding the natural level will have significant negative impacts on human health, ecosystems, climate change, etc. To effectively mitigate ozone and secondary pollution, control measures based on the atmospheric oxidation capacity are necessary.

Ozone has a long atmospheric lifetime and can be transported over long distances to cause regional pollution. The generation mechanism of ozone is complex, and a complicated nonlinear response relationship exists between ozone precursors. The sources of ozone precursors are multifaceted, with various types and significant differences in activity. Therefore, precise control of ozone and precursors is difficult. It is necessary to clarify the mutual contributions between different regions to implement regional joint prevention and control. The complicated meteorological processes and the horizontal and vertical transportation of pollutants need to be determined.

Reasonable and effective emission mitigation strategies for NOx and VOCs must be implemented to improve the science and accuracy of ozone pollution prevention and control. Currently, there is no successful international precedent for the prevention and control of ozone pollution. To achieve this goal, efforts have to be made from the three aspects of science, technology, and policy to enhance research on the formation, transmission, and evolution mechanism of ozone and secondary pollution.

From an international perspective, among the main producing countries of the core patents of "atmospheric oxidation capacity and ozone pollution control" (see Table 2.2.1), China ranks first in terms of the number of core patents, while the average cited number is only 1.53. The USA ranks second in terms of the number of core patents. Germany, France, Japan, and Switzerland have fewer patent publications than China, but their average number of citations has exceeded that of China. This indicates that the amount of research and innovation in the prevention and control of atmospheric oxidation and ozone pollution in China is increasing, but the influence still needs to be enhanced, and pioneering research needs to be improved. In terms of the cooperation network between countries in this development front (see Figure 2.2.1), the degree of international cooperation between different countries is relatively different. As the country with the highest degree of international cooperation, the USA has actively cooperated with Germany, France, China, and Switzerland. Moreover, there is academic cooperation between German and French scholars. In addition to cooperating with American scholars, Chinese scholars mainly focus on independent outputs of core patents.

In terms of the main output institutions of core patents in this engineering development front (see Table 2.2.2), Nanjing University has 14 core patent publications, ranking first, and the average number of core patents cited is 1.5. The institutions with large outputs of core patents in this front in China are mainly universities, which are Nanjing University, South China University of Technology, Zhejiang University, and Beijing University of Technology. The main contributing institutions in the USA are primarily commercial companies. 3M Innovation Co., Ltd. and Xyleco in have the highest proportions of citations, with 11.18% and 15.25%, respectively, and their core patent disclosure rankings are 2 and 7, respectively. Among Chinese institutions, China Petroleum & Chemical Corporation and Foshan Institute of Science and Technology have produced 11 open core patents, but the cited ratios are 0.08% and 0.00%, respectively, indicating that their influence still needs to be further improved. None of the abovementioned institutions have a cooperative relationship in this front, but in the future, China can further enhance cooperation with international institutions. In addition to the USA, China can also strengthen cooperation with countries with greater core patent influence, such as Germany, France, Japan, and Switzerland. In terms of technology development, the "quantitative alone theory" should also be corrected, and relevant comprehensive assessments of the impact of scientific research output should be increased to encourage scientific research institutions to pay attention to the quality and impact of research, promote the integration of production,

Table 2.2.1 Countries with the greatest output of core patents on "atmospheric oxidation capacity and ozone pollution control"

No.	Country	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	China	782	78.20%	1 200	20.15%	1.53
2	USA	91	9.10%	4 126	69.27%	45.34
3	South Korea	34	3.40%	77	1.29%	2.26
4	India	28	2.80%	2	0.03%	0.07
5	Germany	16	1.60%	435	7.30%	27.19
6	France	12	1.20%	182	3.06%	15.17
7	Japan	10	1.00%	206	3.46%	20.60
8	Brazil	5	0.50%	26	0.44%	5.20
9	Russia	5	0.50%	2	0.03%	0.40
10	Switzerland	4	0.40%	65	1.09%	16.25

Table 2.2.2 Institutions with the greatest output of core patents on "atmospheric oxidation capacity and ozone pollution control"

No.	Institution	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	Nanjing University	14	1.40%	21	0.35%	1.50
2	3M Innovation Co., Ltd.	13	1.30%	666	11.18%	51.23
3	Linde AG	12	1.20%	255	4.28%	21.25
4	South China University of Technology	12	1.20%	20	0.34%	1.67
5	China Petroleum & Chemical Corporation	11	1.10%	5	0.08%	0.45
6	Foshan University of Science and Technology	11	1.10%	0	0.00%	0.00
7	Xyleco, USA	10	1.00%	908	15.25%	90.80
8	Zhejiang University	8	0.80%	43	0.72%	5.38
9	Beijing University of Technology	8	0.80%	32	0.54%	4.00
10	BASF AG	7	0.70%	535	8.98%	76.43

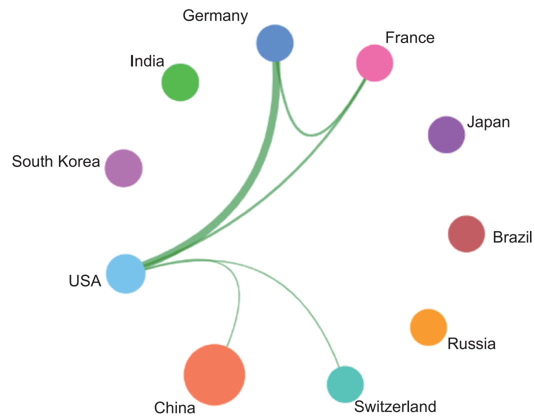

Figure 2.2.1 Collaboration network among major countries in the engineering development front of "atmospheric oxidation capacity and ozone pollution control"

education, and research between university institutions and enterprises, and encourage the rapid development of subject areas.

2.2.2 Marine bionic antifouling technology

Marine fouling is a phenomenon that adversely affects artificial facilities after a large number of marine fouling organisms gather, grow, and reproduce on the surface of artificial facilities. Marine fouling has been affecting and restricting the exploitation and utilization of marine resources since human beings began to carry out marine activities. According to incomplete statistics, the global economic loss caused by marine fouling is as high as tens of billions of dollars annually. The fouling by marine organisms has caused considerable harm to the development of the marine economy. With the improvement in the concept of environmental protection, the conventional antifouling technology has been unable to meet the requirements. Using the natural antifouling ability of marine organisms to develop new, efficient, and environmentally friendly antifouling technology is an important trend in the field of marine antifouling.

Bionic antifouling technology refers to a new non-toxic bionic antifouling coating and method developed using the bionics principle and chemical ecology. It is expected to replace the conventional antifouling coating (which is harmful to the environment) and has a very broad development prospect.

At present, bionic antifouling technology is primarily in the research stage, but it has also achieved certain applications and mainly focuses on microstructural antifouling coatings. The work in this aspect is mainly concentrated in developed countries such as the USA, Japan, and Europe. For example, Gator Sharkote environmental protection antifouling coating developed by the University of Florida in the USA, and "Xie Akte" marine antifouling coating developed by Swedish scientists are outstanding representatives of microstructural antifouling coatings. In addition, the University of Washington and Bremen University of Science and Technology in the USA have developed an organic protective coating based on sharkskin. On the other hand, Japan Kansai Coating Company has constructed a simulated mucus secretion bionic antifouling coating.

Single-factor bionics has some problems, such as an insufficient broad spectrum. The biological antifouling function is not determined by a single factor but by the result of the interaction and mutual influence of two or more factors. This mechanism is called biological coupling. Compared with the single-factor bionic antifouling technology, the multifactor coupling bionic antifouling method is closer to the functional principle of biological prototypes, which is the main trend in bionic antifouling technology development at present. In addition, efficient bionic antifouling agents and increasingly mature controlled-release antifouling coatings are also current development trends.

Table 2.2.3 lists the countries with the greatest output of core patents on "marine bionic antifouling technology". China ranks first in published patents and has a greater quantity compared with other countries. China ranks second in terms of citations and percentage of citations (which are both lower than those of Japan) and ninth in citations per patent. The number of published patents in the USA, Germany, and Denmark is much lower than that in China, but the number of citations per patent is much higher than that of China. This shows that the number of studies and innovations in "marine bionic antifouling technology" in China is increasing, but the influence and creativity of research need to be improved. Figure 2.2.2 depicts the collaboration network among major countries in the engineering development front of "marine bionic antifouling technology." Except for the USA and Japan, international cooperation is relatively lacking, and China only has cooperation with the USA. This shows that China should further promote exchanges and cooperation with other countries in this field.

Table 2.2.4 provides the institutions with the greatest output of core patents on "marine bionic antifouling technology". Of these, nine institutions are from Japan or China. Chugoku Marine Paints, Ltd., Nitto Denko Corporation, and China Shipbuilding Industry Group Co., Ltd. occupy the top three positions in published patents. The top three institutions in terms of citations per patent are Chugoku Marine Paints, Ltd., Hempel A/S, and Asahi Glass Company Co. Ltd. Major R&D institutions are more inclined to develop independently and lack cooperation among institutions. Therefore, Chinese and Japanese institutions still have a wide room for cooperation in this field.

Table 2.2.3 Countries with the greatest output of core patents on "marine bionic antifouling technology"

No.	Countries	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	China	640	64.00%	1 148	26.72%	1.79
2	Japan	211	21.10%	1 614	37.57%	7.65
3	South Korea	52	5.20%	22	0.51%	0.42
4	USA	26	2.60%	335	7.80%	12.88
5	Germany	13	1.30%	740	17.23%	56.92
6	France	10	1.00%	85	1.98%	8.50
7	Denmark	9	0.90%	172	4.00%	19.11
8	Netherlands	9	0.90%	85	1.98%	9.44
9	Norway	7	0.70%	24	0.56%	3.43
10	Israel	6	0.60%	44	1.02%	7.33

Table 2.2.4 Institutions with the greatest output of core patents on “marine bionic antifouling technology”

No.	Institution	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	Chugoku Marine Paints, Ltd.	34	3.40%	591	13.76%	17.38
2	Nitto Denko Corporation	33	3.30%	170	3.96%	5.15
3	China Shipbuilding Industry Group Co., Ltd.	26	2.60%	66	1.54%	2.54
4	Zhejiang Ocean University	21	2.10%	45	1.05%	2.14
5	Sharp Corporation	15	1.50%	35	0.81%	2.33
6	Freshwater Fisheries Research Center of Chinese Academy of Fishery Sciences	14	1.40%	28	0.65%	2.00
7	Asahi Glass Company Co., Ltd.	13	1.30%	79	1.84%	6.08
8	Hempel A/S	10	1.00%	62	1.44%	6.20
9	Furuno Electric Co., Ltd.	10	1.00%	26	0.61%	2.60
10	Hudong-Zhonghua Shipbuilding (Group) Co., Ltd.	9	0.90%	12	0.28%	1.33

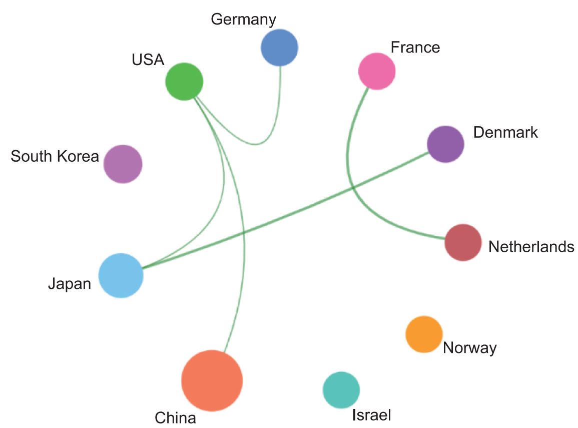

Figure 2.2.2 Collaboration network among major countries in the engineering development front of “marine bionic antifouling technology”

2.2.3 Development of new functional natural cellulose fibers

Functional textiles refer to products that have other special functions (besides providing warmth, covering, and beautification) beyond conventional textile products. According to their function, these textile products can be divided into comfort type, medical health care type, ecological type, protection type, and intelligent functional textile. Among them, the functional characteristics of comfort products are mainly soft and elastic, cool, warm, hygroscopic, quick drying, waterproof and windproof, breathable, and machine washing and ironing. The functional characteristics of medical health care products are primarily manifested as electrotherapy and magnetic therapy, antibacterial deodorization, mildew and pollution prevention, anti-irritability, far-infrared rays, aroma, high water absorption, skin friendly, and moisturizing. The functional characteristics of ecological products are pollution-free, harmless to users, biodegradable, and recyclable in production and use. The functional characteristics of protective products are primarily anti-ultraviolet, flameretardant, antistatic, and anti-electromagnetic radiation. The intelligent products feature heat storage, temperature regulation, color change, shape memory, spontaneous light, positioning and tracking, bionics, monitoring, etc. These special functions can be expressed in a single product, or they can be incorporated into a textile product with composite functions.

The development of society, progress of science and technology, and improvement of living standards have necessitated increasingly higher requirements for textile products, and their functional requirements need to be achieved through innovation and development.

In recent years, China's research investment in the functional development of textiles is among the best in the world, and the development technology of new functional natural cellulose fibers is continuously innovating. As presented in Table 2.2.5, among the technology core patents in recent years, the number of disclosed patents in China is as high as 725, accounting for 72.50% of all disclosed patents. It is followed by Japan and the USA which have 106 and 59, respectively. The total number of patents of new functional natural cellulose fiber development technology in China is much higher than those in Japan, the USA, and other developed countries.

In terms of citation frequency (Table 2.2.5), the number of citations per patent in China is only 0.21, which is far lower than those of developed countries such as the USA, Japan, and Switzerland. The development technology of new functional natural cellulose fibers is still less original, less innovative, and less influential. In terms of patent relevance (Figure 2.2.3), the USA, Japan, and Switzerland are strongly collaborating, while China has a cooperative relationship with France. According to the Top 10 core patent producing institutions (Table 2.2.6), the top three institutions are Kao Corporation of Japan, GK Technology Co., Ltd. of South Korea, and Asahi Kasei Corporation of Japan. China's Donghua University and Xinxiang Hushen Special Fabric Co., Ltd. rank fourth and fifth, respectively, but their patents have not been cited. There is no R&D cooperation between institutions or enterprises in this development front, and the degree of industrialization is low. There is still much room for industry–university–research cooperation in the development of new functional natural cellulose fibers. We should further strengthen exchanges and cooperation with other countries and institutions to enhance China's innovation capacity in this field.

Table 2.2.5 Countries with the greatest output of core patents on "development of new functional natural cellulose fiber"

No.	Country	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	China	725	72.50%	153	7.84%	0.21
2	Japan	106	10.60%	231	11.83%	2.18
3	USA	59	5.90%	908	46.52%	15.39
4	South Korea	40	4.00%	2	0.10%	0.05
5	Germany	17	1.70%	88	4.51%	5.18
6	Switzerland	12	1.20%	340	17.42%	28.33
7	France	11	1.10%	1	0.05%	0.09
8	Sweden	9	0.90%	36	1.84%	4.00
9	India	5	0.50%	2	0.10%	0.40
10	Austria	4	0.40%	0	0.00%	0.00

Table 2.2.6 Institutions with the greatest output of core patents on “development of new functional natural cellulose fiber”

No.	Institution	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	Kaos Corporation	13	1.30%	0	0.00%	0.00
2	GK Technology Co Ltd	9	0.90%	1	0.05%	0.11
3	Asahi Kasei Co Ltd	9	0.90%	0	0.00%	0.00
4	Donghua University	8	0.80%	0	0.00%	0.00
5	Xinxiang Hushen Special Fabric Co Ltd	8	0.80%	0	0.00%	0.00
6	L 'Oreal Cosmetics Group in France	7	0.70%	1	0.05%	0.14
7	Yibin Huimei Fibre New Material Co Ltd	7	0.70%	0	0.00%	0.00
8	Philip Morris Companies Inc	6	0.60%	262	13.42%	43.67
9	Teijin Limited	6	0.60%	6	0.31%	1.00
10	Shinshu University	6	0.60%	0	0.00%	0.00

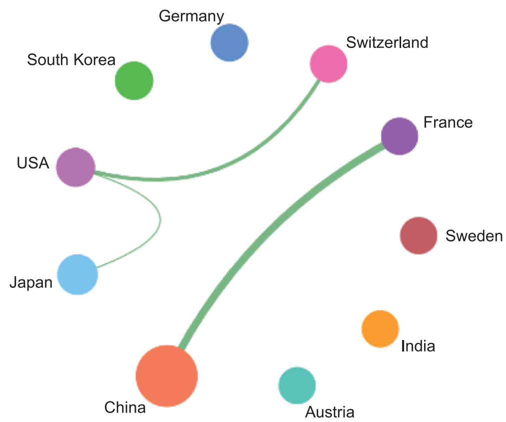

Figure 2.2.3 Collaboration network among major countries in the engineering development front of “development of new functional natural cellulose fiber”

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