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 2016 and 2021 are summarized in Tables 1.1.1 and 1.1.2, respectively.

(1) Mechanisms of multi-media transport and transformation of new pollutants

New pollutants (or emerging pollutants) refer to newly discovered or noticed pollutants that pose risks to the ecological environment or human health, and have not yet been incorporated into management or existing management measures are insufficient to effectively prevent and control their risks. With the increasing understanding of the environmental and health hazards of chemical substances and the continuous development of environmental monitoring technology, the number of new pollutants that can be identified will continue to increase. Therefore, the development of efficient and universal analytical methods for discovering new pollutants is an important research direction in the field of new pollutant management.

The production and use of toxic and hazardous chemical substances are the main sources of new pollutants. Literature shows that higher levels of new pollutants such as environmental endocrine disruptors, antibiotics, and microplastics have been monitored successively in the atmosphere, water, and soil in some regions of China. Transfer of new pollutants among different environmental media often occurs, implying that one medium can become the pollution source for the next environmental medium, leading to differences in fate and contamination levels for new pollutants in different media. However, the migration and transformation

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	Mechanisms of multi-media transport and transformation of new pollutants	117	7 863	67.21	2017.8
2	Treatment and resource recovery techniques for hypersaline wastewater	81	4 877	60.21	2019.0
3	Mechanism and critical path of synergies between atmospheric pollution control and carbon emission mitigation	918	80 741	87.95	2017.8
4	Ecological effects and risks of microplastics in coastal wetlands or offshore waters	20	463	23.15	2020.5
5	Carbon sequestration of coastal wetland ecosystem	73	4 816	65.97	2018.3
6	Application of machine learning in earth system observation and prediction	96	9 270	96.56	2017.9
7	Vital characteristics and ecological effects of microorganisms in extreme marine environments	17	1 378	81.06	2017.9
8	Research on the cleaner production technology of tanning agent-free leather making	24	130	5.42	2019.8
9	Study on the mechanisms of food functional factors and chronic metabolic syndrome	18	1 524	84.67	2018.2
10	Extraction and development of new natural cellulose fibers	43	5 705	132.67	2017.5

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	2016	2017	2018	2019	2020	2021
1	Mechanisms of multi-media transport and transformation of new pollutants	36	16	25	22	13	5
2	Treatment and resource recovery techniques for hypersaline wastewater	0	0	31	30	13	7
3	Mechanism and critical path of synergies between atmospheric pollution control and carbon emission mitigation	202	204	203	158	109	35
4	Ecological effects and risks of microplastics in coastal wetlands or offshore waters	0	0	1	3	2	14
5	Carbon sequestration of coastal wetland ecosystem	0	17	28	21	5	2
6	Application of machine learning in earth system observation and prediction	10	12	13	30	17	0
7	Vital characteristics and ecological effects of microorganisms in extreme marine environments	0	6	7	4	0	0
8	Research on the cleaner production technology of tanning agent-free leather making	0	0	4	5	8	7
9	Study on the mechanisms of food functional factors and chronic metabolic syndrome	3	4	4	2	3	2
10	Extraction and development of new natural cellulose fibers	13	8	11	8	3	0

behaviors and mechanisms of most new pollutants among multi-media are unclear, and the health risks are unclear. Around the management of new pollutants, it is necessary to further strengthen the research on environmental screening, traceability studies, environmental risk assessment and control, and research on ecological and environmental hazard mechanisms such as antibiotics and microplastics; it is also a necessary to develop with the help of mathematical methods or models to better describe the cross-media migration and transformation of new pollutants released into the atmosphere.

(2) Treatment and resource recovery techniques for hypersaline wastewater

Hypersaline wastewater usually refers to wastewater containing dissolved salts above 3.5% (w/v). It is extensively present in the chemical industry and often contains a large number of hazardous substances such as refractory organic matters and heavy metals. In recent years, with the policies on “zero liquid discharge” and wastewater recycling vigorously promoted across the world, the development of technologies for treating and recycling hypersaline wastewater has now become a high priority in the area of water treatment.

The high-concentration inorganic ions in hypersaline wastewater would not only inhibit bacterial growth but also quench hydroxyl radicals, thus constraining organic pollutant degradation. Regarding organic pollutants removal, the current research is mostly focused on advanced oxidation technologies such as persulfate-based Fenton and spatially confined electro-catalysis. The core concept is to increase the lifetime of active species and accelerate the mass transfer of reactants for enhanced pollutants degradation. Besides, more halotolerant and halophilic bacteria have been screened and domesticated, which contributes to the removal of organic pollutants in combination with bioaugmentation technologies such as membrane bioreactors and granular sludge reactors.

Since salts and water in hypersaline wastewater are valuable resources, their separation is essential for establishing a sustainable water treatment process. Two of the important research fields are the concentration of hypersaline wastewater and the separation of mixed salts. Regarding these demands, membrane separation technologies, including nanofiltration, reverse osmosis, selective electrodialysis, and membrane distillation, have attracted much attention. To realize the industrial application of membrane technologies in the recycling of hypersaline wastewater, it’s essential to fabricate high-performance membrane materials and develop membrane fouling control technologies.

It is noteworthy that the recycling of hypersaline wastewater is highly impacted by its complex composition. Therefore, multiprocess integrated approaches should be developed based on the actual water quality to accomplish the recycling of hypersaline wastewater in a green, low-carbon, and efficient manner.

(3) Mechanism and critical path of synergies between atmospheric pollution control and carbon emission mitigation

Both atmospheric pollutant emissions and CO_2 emissions show agglomeration effects in space, and the grids of hotspots are highly consistent. These hotspots are mainly distributed in large and medium-sized cities such as provincial capitals (capitals of autonomous regions) and key urban agglomerations. Similar to pollutant emissions, PM2.5 pollution and O_3 pollution in China also show obvious regional characteristics, and the areas with heavy air pollution and CO_2 emission areas are highly overlapped. The same root and homology of greenhouse gases and atmospheric pollutants makes the emission reduction work direction highly consistent, and the coordinated governance work can simultaneously achieve the dual goals of in-depth pollution prevention and control and "carbon peaking and carbon neutrality", and promote the reduction of carbon emissions. Synergistic effect of pollution reduction and carbon reduction.

Considering that environmental pollutants and greenhouse gases have the same root and the same source, pollution reduction and carbon reduction are highly consistent in terms of management and control ideas, management methods, task measures, etc., and can be planned, integrated, and coordinated to achieve cost reduction and efficiency. Therefore, it is necessary to reveal the comprehensive impact mechanism of the application of pollution reduction and carbon reduction technology on social economy, ecosystem and human health through key research, as well as the feedback mechanism of cross-system element coupling and linkage on different technologies, and calculate the energy saving and emission reduction potential of the circular economy development model. Quantitative simulation and targeted regulation methods for the synergy of material energy flow and pollution reduction and carbon reduction in the coupled system of man and nature, develop a coupled multi-scale economy-energy-environment-climate model, and combine multi-source data from the Internet of Things and the Internet to reduce atmospheric pollution and carbon emissions Carry out accurate detection and evaluation, develop technologies and methods for collaborative governance of greenhouse gases and air pollutants, explore key paths for collaborative governance, and form a technical system and decision-making system support to achieve the goal of carbon neutrality.

(4) Ecological effects and risks of microplastics in coastal wetlands or offshore waters

Microplastics are plastic particles, fibers, films or fragments less than 5 mm in diameter, which are difficult to degrade in the natural environment and can persist and migrate over long distances as microplastics are petroleum-based and carbon-chain polymers. Microplastics can alter the physicochemical properties of the abiotic environment and cause toxic damage to the growth traits and physiological and biochemical characteristics of plants, animals and microorganisms. Meanwhile, microplastics can release chemical additives such as Bisphenol A (BPA), phthalates and antioxidants during natural aging. In addition, microplastics are able to carry pathogenic microorganisms and other contaminants such as heavy metals, antibiotics and endocrine disruptors, and finally form complex contamination.

In recent years, there have been increasing studies on the environmental behavior and toxicological effects of microplastics in terrestrial and marine ecosystems. In contrast, few works have been conducted on microplastic pollution in coastal wetlands or offshore waters. Coastal wetlands and offshore waters play an important role in maintaining the balance between land and sea, protecting biodiversity, and improving the coastal environment. Seaward rivers have been identified as an important transport pathway for terrestrial plastic debris into the ocean. As a transition zone between terrestrial and marine ecosystems, coastal wetlands and offshore waters have become filters and sinks for microplastics. Offshore pollution from ship traffic, fisheries, oil well exploration, coastal agriculture and tourism is another important source of microplastics in the marine environment. At the same time, microplastics in the ocean can be transported back to coastal wetlands and offshore waters by wind-driven, ocean current circulation and tidal flows. Microplastic pollution in coastal wetlands and offshore waters is becoming more and more serious, but the ecological risks posed by microplastics to coastal wetlands or offshore waters are not yet clear. Therefore, the distribution characteristics and transport pathways of microplastics in coastal wetlands and offshore waters need to be further investigated, and the toxic mechanisms and ecological effects of microplastics on the ecosystem structure and function of coastal wetlands and offshore waters need to be further clarified.

(5) Carbon sequestration of coastal wetland ecosystem

Out of all the biological carbon captured in Earth's ecosystems, over half (55%) is captured by marine living organisms, which is called "blue carbon" (relative to the "green carbon" fixed by terrestrial ecosystems). The coastal wetland ecosystems mainly including mangroves, salt marsh wetlands and seagrass beds. The carbon captured by them is called coastal blue carbon. Compared with other ecosystems, the coastal wetland ecosystems have a very high carbon sequestration rate. In addition, the coastal wetland ecosystems are located between the sea and land, which are significantly affected by sea-land interactions. They are also eco-fragile regions and sensitive environmental areas that are greatly affected by human activities and climate change. Protecting and repairing the coastal wetland ecosystems and restoring the lost wetlands are contribute to carbon neutrality goals. Therefore, the study of carbon sequestration in coastal wetland ecosystems has received extensive attention in recent years.

At present, there have been many studies on blue carbon storage and carbon sequestration potential, but the carbon measurement methods used in different regions are not the same, which is not conducive to the comprehensive comparison and global analysis of coastal blue carbon. Besides, the carbon sink capacity of coastal wetland ecosystem is dynamic, and its carbon sequestration potential under the dual impact of climate change and human activities is also full of uncertainty. In response to these problems, the current main research directions and development trends include: first, it is necessary to study how to reduce the uncertainty in assessment of blue carbon in the coastal wetland ecosystems, deepen the understanding of carbon sequestration mechanism, and establish carbon sink measurement and assessment systems; second, it is necessary to analyze the impact of climate change and human activities on coastal wetland ecosystems and explain its evolution; third, it is necessary to study the technologies of carbon sequestration, assess the potential and stability of carbon sink enhancement in coastal wetland ecosystems, explore the protection, restoration and management methods for coastal wetland ecosystems based on natural solutions, and realize the synergistic improvement of the carbon sequestration and sink enhancement function of coastal wetland ecosystems and other important ecosystem functions; forth, it is necessary to select typical coastal wetlands, conduct evaluation and technology demonstration, and finally realize engineering and large-scale application.

(6) Application of machine learning in earth system observation and prediction

Driven by an in-depth understanding of the mechanisms of the climate system, observational data, reanalysis data, and numerical simulations of the Earth system have grown rapidly over the past 40 years. In particular, a large number of climate models have participated in the fifth and the sixth phase of the International Coupled Model Intercomparison Project (CMIP5 and CMIP6), providing tens of billions of bytes of data resources for research on climate change, climate prediction and climate projection. How to extract useful information and acquire new knowledge from "big data" poses new challenges to traditional analysis methods, and brings new opportunities for machine learning and artificial intelligence. Machine learning can summarize key information and main features from the "big data" of the earth system, so as to make accurate identification and prediction. For example, the sea surface temperature information of a key area can improve the climate prediction skills of a certain area on the land in the coming months; on this basis, artificial intelligence can provide automated early warning of extreme weather and climate events. At present, machine learning, especially deep learning, has been widely studied in convective short-term nowcasting, extreme event detection and improvement of numerical weather models and their forecast error correction. The next step will be to change the traditional meteorological observation model, to accelerate and improve the processing of meteorological observation data, improve the quality of numerical weather forecasting, and advance the intersection of earth sciences.

(7) Vital characteristics and ecological effects of microorganisms in extreme marine environments

Extreme marine environments such as the deep sea, Polar Regions, submarine hydrothermal regions, and cold springs are characterized by harsh environmental conditions, including abnormal salinity, pressure, temperature, acidity, alkalinity, and radiation intensity. Nonetheless, a large number of extremophilic microorganisms survive these conditions. Investigating microorganisms that inhabit extreme marine environments, with their diversity, unique biological structures, and novel metabolic mechanisms, provides a valuable source of knowledge for exploring the origin, adaptation, and evolution of life. Moreover, marine extremophiles can produce novel active substances, including enzymes and other natural products, with broad potential uses. In addition, marine extremophiles are responsible for mineralizing and reusing organic matter in specific habitats as drivers of the transfer of nutrients, energy, and biogeochemical cycles.

At present, the primary research focuses are community structure and ecological functions of marine extremophiles, their symbiotic relationships with benthic organisms, their adaptation and evolutionary mechanisms for survival in extreme environments, the extraction of active substances from extremophiles, and their participation in biogeochemical cycling processes and environmental effect. In the future, it will be necessary to improve marine extremophile isolation and cultivation capabilities and to analyze their genetic structures and physiological metabolisms. It will also be essential to characterize the mode of action of their active products, explore their roles and interactions in the ecological processes of extreme environments, and elucidate their influence and regulatory functions on extreme environmental ecosystems.

(8) Research on the cleaner production technology of tanning agent-free leather making

Chrome tanning technology based on the theory of "cross-linking tanning" occupies a dominant position in leather manufacturing, but the conventional chrome tanning technology suffers from the chrome emission issue. To address this problem, tanning chemists have developed chrome-free tanning agents represented by non-chrome metal tanning agents and organic tanning agents, which is aimed to replace conventional chrome tanning agents to form cross-linkages among collagen fibers to obtain tanning effects so as to fundamentally solve the problem of chrome emission. Nevertheless, the existing chrome-free tanned leathers fail to provide comparable thermal stability, mechanical strength and other leather properties to chrome-tanned leathers. In addition, the chrome-free tanning techniques still suffer from the emission problems of metals and organic pollutants. Aiming at the bottleneck of chrome-free tanning technologies based on the existing "cross-linking tanning" theory, it is of great significance to develop new tanning theories and tanning technologies to achieve cleaner production in the leather industry. During the conversion of raw hide into leather, its water content is significantly reduced, which also shows obviously improved fiber dispersion and porosity. Therefore, the tanning process can be regarded as a "controllable dehydration" process involved with reduced hydrophilicity and improved fiber dispersion. In these considerations, controllable removal of free water in raw hides with suitable dehydration media is expected to impart collagen fibers with high dispersibility and porosity, thereby significantly enhancing the thermal stability, mechanical strength and other leather properties without the usage of cross-linking agents. Hence, the pollutant emission problems in leather industry are able to be radically resolved, thus boosting the realization of cleaner production of tanning agent-free leather making. Polar organic solvents have the capabilities to provide efficient dehydration role, which are able to be applied in reducing the water content of raw hide effectively. However, the water distribution between organic solvent and raw hide will gradually reach a balance along with the dehydration to proceed, which requires multiple organic solvent changes to achieve deep dehydration performance, thus resulting some problems such as excessive consumption of organic solvents, complicated dehydration process and difficulty in recycling of waste solvents. To this end, the composite dehydration media composed of porous materials and polar organic solvents was developed for realizing the one-step controllable deep dehydration. The porous materials are capable of selectively adsorbing and storing the captured water in the organic solvents, thereby breaking the distribution balance of water between the organic solvent and raw hide. Moreover, the used composite dehydration media were facilely recycled through the solid-liquid separation and reused for tanning agent-free leather making after regeneration. In the future, it is essential to further develop novel composite dehydration media to strengthen the controllable deep dehydration performance of raw hides and consummate the technical routes of tanning agent-free leather making, which in turn lays the foundation for the industrial application of cleaner production technology of tanning agent-free leather making so as to promote the sustainable and green development of the leather industry.

(9) Study on the mechanisms of food functional factors and chronic metabolic syndrome

Food functional factors such as polysaccharides, polyphenols and flavonoids in animals, plants and fungi have many excellent biological activities such as preventing obesity and diabetes, regulating glucolipid metabolism, and improving obesity induction, which have positive effects on improving human health. Therefore, it is important to study the mechanism of food functional factors in the prevention of chronic metabolic syndrome at molecular, cellular and overall levels to provide theoretical and technical support for the early prevention and nutritional intervention of nutrition-related chronic diseases. Meanwhile, the enrichment of food functional factors and their bioactive system evaluation will be studied and functional foods with applications for the prevention of metabolic syndrome will be developed. Rapid and efficient screening and identification of natural functional components (such as terpenoids, flavonoids, phenols, alkaloids, saponins, etc.) in new food ingredients that act on obesity, diabetes, immunity, hypertension, lipid dysfunction and cancer through modern molecular biology, cell biology, metabolomics, molecular nutrition and other biological, chemical, physical and chemical technologies.

(10) Extraction and development of new natural cellulose fibers

Since petrochemical resources are becoming more scarce and environmental problems are becoming increasingly significant, natural cellulose fibers have gained increasing attention for their green, clean, and environmentally friendly characteristics, unique properties, renewable raw materials, natural degradation after disposal, and non-toxic and harmless properties. Natural cellulose fiber is a type of natural fiber containing cellulose as the main component. Since it is derived from plants, it is also referred to as plant fiber. The natural cellulose fiber is environmentally friendly. It is of great significance to the sustainable use of natural resources and the protection of the environment to conduct research and development of new natural cellulose fibers.

There are currently several research difficulties associated with the cellulose science field: one is the extraction of natural cellulose fibers; the second is the research of cellulose dissolving systems; and the third is the development of new functional natural cellulose fibers. It is particularly important to know how to cleanly and efficiently separate cellulose from plant cell walls (natural fibers). Plants have a very complex cell wall structure. The outer layer is protected by wax and inorganic salts. Chemical components such as hemicellulose and lignin are closely related to the inner cellulose. All of these factors pose obstacles to the separation and extraction of cellulose. There are two types of separation and extraction techniques that are commonly used today: biological and chemical. After biological extraction, cellulose contains a significant amount of gum, and the activity of biological enzymes is poor. The chemical method is the most widely used, but it also involves a complex process and consumes a great deal of energy. To further realize the development of high value-added functional natural cellulose fiber textiles, it is necessary to pursue the green and efficient separation, extraction, and research and development of new natural cellulose fibers.

1.2 Interpretations for three key engineering research fronts

1.2.1 Mechanisms of multi-media transport and transformation of new pollutants

New pollutants (or emerging pollutants) refer to newly discovered or noticed pollutants that pose risks to the ecological environment or human health, and have not yet been incorporated into management or existing management measures are insufficient to effectively prevent and control their risks. With the increasing understanding of the environmental and health hazards of chemical substances and the continuous development of environmental monitoring technology, the number of new pollutants that can be identified will continue to increase. Therefore, the development of efficient and universal analytical methods for discovering new pollutants is an important research direction in the field of new pollutant management. Figure 1.2.1 is the roadmap of the engineering research front of “mechanisms of multi-media transport and transformation of new pollutants”.

The production and use of toxic and hazardous chemical substances are the main sources of new pollutants. Literature shows that higher levels of new pollutants such as environmental endocrine disruptors, antibiotics, and microplastics have been monitored successively in the atmosphere, water, and soil in some regions of China. Transfer of new pollutants among different environmental media often occurs, implying that one medium can become the pollution source for the next environmental medium, leading to differences in fate and contamination levels for new pollutants in different media. However, the migration and transformation behaviors and mechanisms of most new pollutants among multi-media are unclear, and the health risks are unclear. Around the management of new pollutants, it is necessary to further strengthen the research on environmental screening, traceability studies, environmental risk assessment and control, and research on ecological and environmental hazard mechanisms such as antibiotics and microplastics; it is also a necessary to develop with the help of mathematical methods or models to better describe the cross-media migration and transformation of new pollutants released into the atmosphere.

Table 1.2.1 shows countries with the largest output of core papers on "mechanisms of multi-media transport and transformation of new pollutants". Among them, China ranked first with 42.74% of core papers and 3 637 citations. There is a large gap between other countries and China, which indicates that China has strong research advantages in this field. In terms of citations per paper, although the number of core papers in Spain is small, its citations per paper rank first, which also shows the importance of publishing high-level core papers recognized by peers from one side.

Table 1.2.2 shows the main output institutions of core papers in this engineering research frontier. Six of the top ten output institutions are from Chinese research institutions, namely, Chinese Academy of Sciences, East China Normal University,

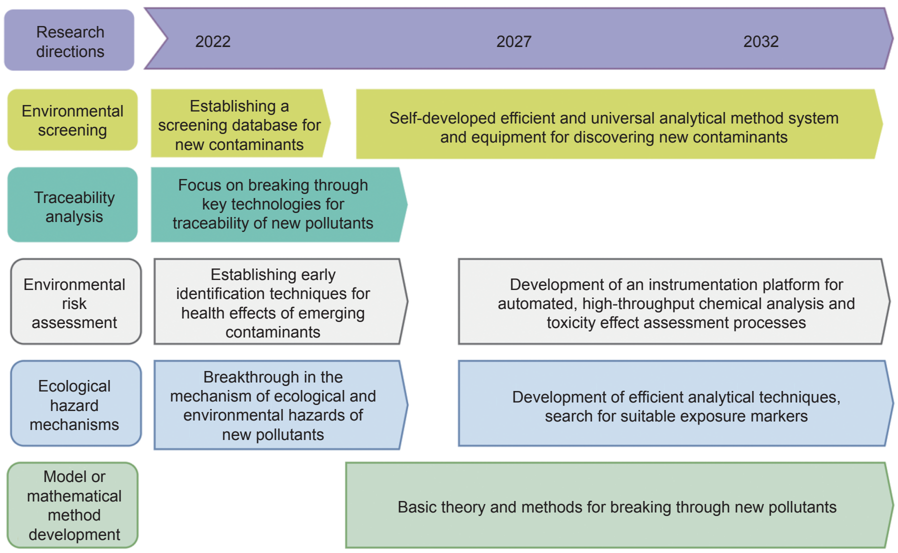


Figure 1.2.1 Roadmap of the engineering research front of "mechanisms of multi-media transport and transformation of new pollutants"

Table 1.2.1 Countries with the greatest output of core papers on "mechanisms of multi-media transport and transformation of new pollutants"

No.	Country	Core papers	Percentage of core/% papers	Citations	Citations per paper	Mean year
1	China	50	42.74	3 637	72.74	2018.0
2	USA	17	14.53	1 093	64.29	2018.2
3	India	10	8.55	590	59.00	2017.6
4	UK	8	6.84	509	63.62	2017.9
5	Germany	8	6.84	430	53.75	2017.9
6	Spain	7	5.98	585	83.57	2018.0
7	France	7	5.98	360	51.43	2017.9
8	Italy	6	5.13	357	59.50	2016.7
9	Norway	6	5.13	347	57.83	2016.5
10	Turkey	6	5.13	325	54.17	2017.3

Tsinghua University, Guangdong University of Technology, Northwest A&F University, and Nankai University. Among them, Chinese Academy of Sciences ranked first in the number of institutions with 20 core papers.

As can be seen from Figure 1.2.2, more emphasis is placed on inter-country cooperation in this research area by China, the USA, India, and the UK. China has the highest number of published papers, mainly with India, the UK, and Germany for collaborative publication. According to Figure 1.2.3, Chinese Academy of Sciences, Norwegian Institute of Air Research, Nankai University, and East China Normal University have cooperative relations.

Based on Table 1.2.3, the country with the highest output of citing core papers is China, with 46.41% of citing core papers, followed by the USA with 12.31%. As presented in Table 1.2.4, the institution with the highest output of citing core papers is Chinese Academy of Sciences, with 36.12% of citing core papers, followed by Hunan University, with 12.15% of citing core papers.

The results of the above data analysis show that China is the forefront of the world in the output and the number of citing core papers on the mechanism of multi-media transport and transformation of new pollutants, followed by the USA.

1.2.2 Carbon sequestration of coastal wetland ecosystem

The carbon fixed by the coastal wetland ecosystems such

Table 1.2.2 Institutions with the greatest output of core papers on "mechanisms of multi-media transport and transformation of new pollutants"

No.	Institution	Core papers	Percentage of core/% papers	Citations	Citations per paper	Mean year
1	Chinese Academy of Sciences	20	17.09	945	47.25	2017.3
2	East China Normal University	4	3.42	453	113.25	2018.5
3	Tsinghua University	4	3.42	388	97.00	2019.2
4	Norwegian Institute for Air Research	4	3.42	259	64.75	2016.2
5	Environment and Climate Change Canada	4	3.42	237	59.25	2016.8
6	Central University of South Bihar	4	3.42	206	51.50	2016.5
7	Guangdong University of Technology	3	2.56	527	175.67	2018.3
8	Northwest A&F University	3	2.56	382	127.33	2019.7
9	Masaryk University	3	2.56	245	81.67	2016.0
10	Nankai University	3	2.56	188	62.67	2018.7

Figure 1.2.2 Collaboration network among major countries in the engineering research front of "mechanisms of multi-media transport and transformation of new pollutants"

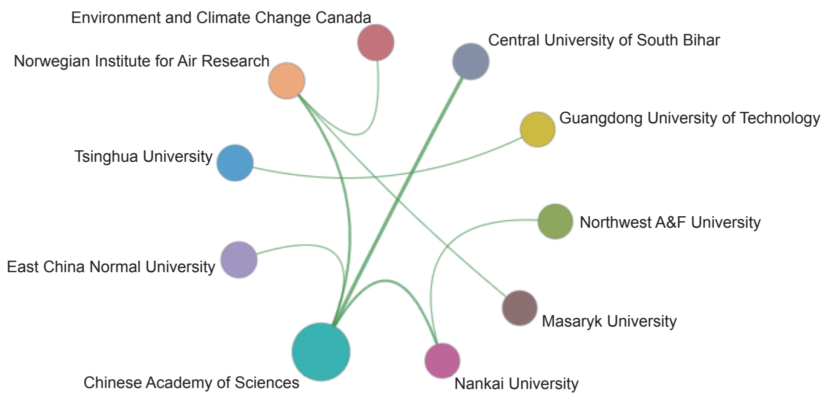


Figure 1.2.3 Collaboration network among major institutions in the engineering research front of "mechanisms of multi-media transport and transformation of new pollutants"

Table 1.2.3 Countries with the greatest output of citing papers on "mechanisms of multi-media transport and transformation of new pollutants"

No.	Country	Citing papers	Percentage of citing papers/%	Mean year
1	China	3 083	46.41	2020.1
2	USA	818	12.31	2020.0
3	India	445	6.70	2020.1
4	Germany	332	5.00	2019.9
5	UK	321	4.83	2020.0
6	Canada	314	4.73	2019.8
7	Spain	293	4.41	2020.0
8	Italy	287	4.32	2019.8
9	Australia	260	3.91	2020.1
10	France	256	3.85	2019.9

Table 1.2.4 Institutions with the greatest output of citing papers on "mechanisms of multi-media transport and transformation of new pollutants"

No.	Institution	Citing papers	Percentage of citing papers/%	Mean year
1	Chinese Academy of Sciences	523	36.12	2019.8
2	Hunan University	176	12.15	2019.0
3	Tsinghua University	109	7.53	2019.9
4	Nanjing University	88	6.08	2020.1
5	Northwest A&F University	86	5.94	2020.5
6	East China Normal University	83	5.73	2020.0
7	Jinan University	83	5.73	2019.9
8	Nankai University	79	5.46	2020.2
9	Peking University	78	5.39	2020.0
10	Tongji University	72	4.97	2020.1

as mangrove, salt marsh wetland and seagrass bed are the coastal blue carbon. The term “blue carbon” was first coined in 2009. Compared with the “green carbon” fixed by terrestrial ecosystems, it emphasizes the important contribution of ocean to carbon sequestration. The carbon sequestration of coastal wetland ecosystems is mainly reflected in plant carbon sequestration and sediment carbon burial in the vertical direction, and carbon exchange with seawater in the horizontal direction. The reciprocating tidal can slow down the decomposition of organic matter, continuously accumulate of the sediments and create an anaerobic environment in the coastal wetlands. The decomposition of organic matter is inhibited, and the carbon in the sediments can be kept in a stable state for a long time under certain conditions and realize continuous carbon storage. Compared with other ecosystems, the coastal wetland ecosystems have a very high carbon sequestration rate. In addition, the coastal wetlands also provide ecosystem service functions such as storm protection, wave dissipation, climate regulation, water purification, spiritual and aesthetic, and nutrient cycling, which has significant social and economic benefits.

The protection and restoration of the coastal ecosystems under human intervention is an operable way to increase carbon sinks. The existing technologies for coastal wetland restoration to increase carbon sinks include rebuilding high biomass plant communities, amending the sediment, conservating the beach, improving the wetland soil and the water environment. At present, the “nature-based solutions” are mainly advocated to realize the synergistic improvement of the carbon sequestration and sink enhancement of coastal wetland ecosystems and other important ecosystem functions. Figure 1.2.4 is the roadmap of the engineering research front of “carbon sequestration of coastal wetland ecosystem”.

The main research directions and development trends at present include: ① analyzing the carbon source and carbon fixation mechanism, establishing the monitoring network, the big data platform, and carbon assessment systems, achieving long-term real-time monitoring; ② based on the spatial-temporal pattern of blue carbon, exploring the key regulatory factors of climate change and human activities that affect the blue carbon, deepening the understanding of carbon sequestration mechanism and evolution, and assessing the potential and sustainability of coastal wetland ecosystems in increasing carbon sinks; ③ studying the technologies of carbon sequestration, assessing the potential and stability of carbon sink enhancement in coastal wetland ecosystems, establishing the frameworks for coastal wetlands protection, restoration and management based on natural solutions, studying the service value evaluation methods of the coastal wetland ecosystems, exploring how to protect the integrity of coastal wetland ecosystems functions, and realizing the coordinated improvement of carbon sequestration and sink enhancement and other ecosystem functions; ④ selecting typical coastal wetlands, conduct evaluation and technology demonstration, and realizing the engineering and large-scale application of technologies for synergistic improvement of various ecosystem functions.

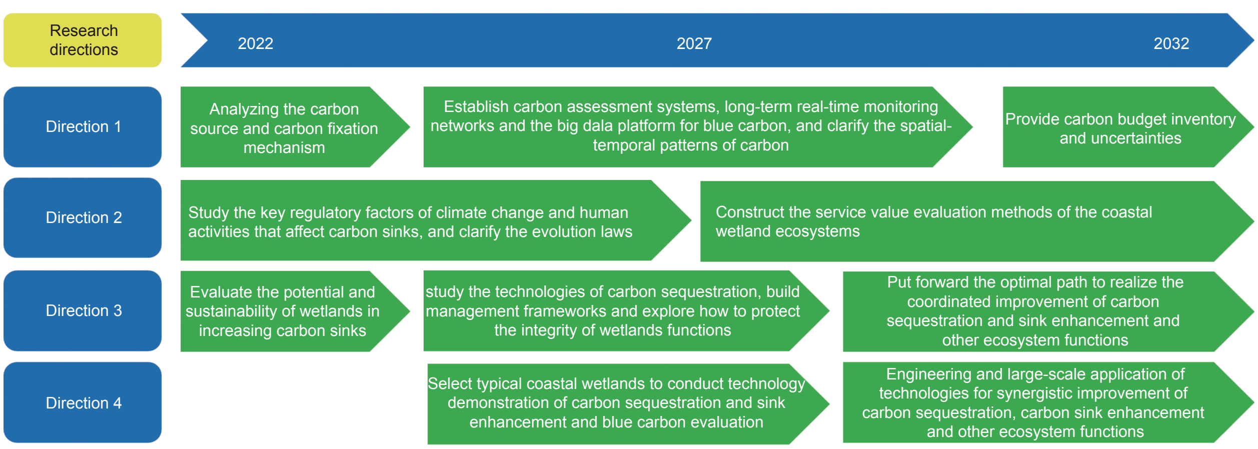


Figure 1.2.4 Roadamp of the engineering research front of “carbon sequestration of coastal wetland ecosystem”

Among the countries with the greatest output of core papers on this research (Table 1.2.5), the number of core papers and citation frequency of the USA are the first, and the number of core papers of China is the second. The total number of core papers of China and the USA accounts for more than half of the total number of the top 10 countries. In terms of the collaboration network among major countries on this research (Figure 1.2.5), the cooperation among the top 10 countries is close. In terms of institutions with the greatest output of core papers on this research (Table 1.2.6), the top 10 institutions with core papers are concentrated in China and the USA. In the collaboration network among major institutions (Figure 1.2.6), there is close cooperation among various institutions. In the ranking of countries with the greatest output of citing papers (Table 1.2.7), China ranks first, while the Chinese Acad Sci, Beijing Normal Univ and East China Normal Univ rank first, second and fifth respectively in the ranking of institutions with the greatest output of citing papers (Table 1.2.8). In short, although the USA is still in the leading position in the world, China has also accelerated the pace of catching up. China still needs to accelerate its development, narrow the gap with the USA, and improve the international influence and discourse power of research in this field.

Table 1.2.5 Countries with the greatest output of core papers on "carbon sequestration of coastal wetland ecosystem"

No.	Country	Core papers	Percentage of core papers/%	Citations	Citations per paper	Mean year
1	USA	43	58.90	3 311	77.00	2018.1
2	China	30	41.10	1 728	57.60	2018.4
3	Australia	18	24.66	1 944	108.00	2018.5
4	UK	9	12.33	1 525	169.44	2018.3
5	Germany	8	10.96	522	65.25	2018.2
6	Netherlands	7	9.59	1 323	189.00	2018.0
7	Canada	7	9.59	487	69.57	2018.6
8	Spain	5	6.85	310	62.00	2018.6
9	Belgium	4	5.48	276	69.00	2018.0
10	Brazil	3	4.11	977	325.67	2018.3

Figure 1.2.5 Collaboration network among major countries in the engineering research front of "carbon sequestration of coastal wetland ecosystem"

Table 1.2.6 Institutions with the greatest output of core papers on "carbon sequestration of coastal wetland ecosystem"

No.	Institution	Core papers	Percentage of core papers/%	Citations	Citations per paper	Mean year
1	Chinese Academy of Sciences	9	12.33	519	57.67	2018.8
2	University of Maryland	8	10.96	1 204	150.50	2017.9
3	Nature Conservancy	7	9.59	1 389	198.43	2018.1
4	U.S. Geological Survey	7	9.59	430	61.43	2018.0
5	Beijing Normal University	6	8.22	294	49.00	2018.7
6	University of Aberdeen	5	6.85	1 261	252.20	2018.6
7	Smithsonian Environmental Research Center	5	6.85	346	69.20	2018.6
8	University of California, Berkeley	5	6.85	328	65.60	2018.4
9	Woods Hole Research Center	4	5.48	1 236	309.00	2018.5
10	University of Florida	4	5.48	1 016	254.00	2017.8

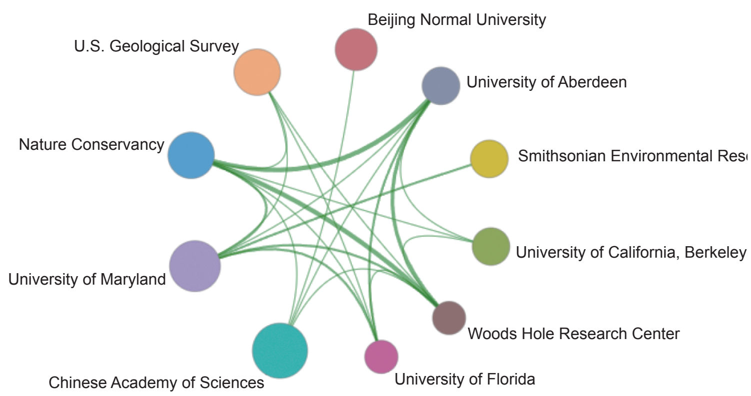


Figure 1.2.6 Collaboration network among major institutions in the engineering research front of "carbon sequestration of coastal wetland ecosystem"

Table 1.2.7 Countries with the greatest output of citing papers on "carbon sequestration of coastal wetland ecosystem"

No.	Country	Citing papers	Percentage of citing papers/%	Mean year
1	China	1 411	26.56	2020.3
2	USA	1 395	26.26	2020.2
3	UK	513	9.66	2020.3
4	Australia	478	9.00	2020.2
5	Germany	389	7.32	2020.3
6	Canada	260	4.89	2020.3
7	France	197	3.71	2020.3
8	Netherlands	191	3.60	2020.2
9	Spain	171	3.22	2020.3
10	Italy	160	3.01	2020.3

Table 1.2.8 Institutions with the greatest output of citing papers on “carbon sequestration of coastal wetland ecosystem”

No.	Institution	Citing papers	Percentage of citing papers/%	Mean year
1	Chinese Academy of Sciences	465	35.33	2020.3
2	Beijing Normal University	129	9.80	2020.3
3	U.S. Geological Survey	126	9.57	2020.0
4	University of California, Berkeley	102	7.75	2020.2
5	East China Normal University	88	6.69	2020.5
6	Nature Conservancy	83	6.31	2020.0
7	University of Maryland	69	5.24	2020.0
8	U.S. Forest Service	69	5.24	2020.1
9	University of Queensland	66	5.02	2020.0
10	Stanford University	60	4.56	2020.2

1.2.3 Research on the cleaner production technology of tanning agent-free leather making

Tanning refers to the qualitative transformation process of converting raw hide into leather, which is one of the most important sections in the leather manufacturing. Chrome tanning technology based on the usage of chrome salts as tanning agents occupies a dominant position in leather manufacturing for a long time due to its excellent cross-linking tanning effect. However, chrome emission is a persisting problem in chrome tanning process, which is suffered by the limited absorption capability of raw hide to chrome tanning agent. To address this issue, great efforts have been dedicated to developing chrome-free tanning techniques based on the “cross-linking tanning” theory, which is aimed to replace conventional chrome tanning agents to form cross-linkages among collagen fibers to obtain tanning effects so as to fundamentally solve the problem of chrome emission. At present, the already reported chrome-free tanning agents mainly include non-chrome metal tanning agents and organic tanning agents, while these chrome-free tanned leathers fail to provide comparable thermal stability, mechanical strength and other leather properties to chrome-tanned leathers. In addition, the chrome-free tanning techniques still suffer from the emission problems of metals and organic pollutants. Figure 1.2.7 is the roadmap of the engineering research front of “research on the cleaner production technology of tanning agent-free leather making”.

Aiming at the bottleneck of chrome-free tanning technologies based on the existing “cross-linking tanning” theory, it is of great significance to develop new tanning theories and tanning technologies to achieve cleaner production in the leather industry. Extensive tanning practices indicate that the tanned leather has lower water content as compared with raw hide, which also shows obviously improved fiber dispersion and porosity. Therefore, the tanning process can be regarded as a “controllable dehydration” process involved with reduced hydrophilicity and improved fiber dispersion. In these considerations, controllable removal of free water in raw hides with suitable dehydration media is expected to impart collagen fibers with high dispersibility and porosity, thereby significantly enhancing the thermal stability, mechanical strength and other leather properties without the usage of cross-linking agents. Hence, the pollutant emission problems in leather industry are able to be radically resolved, thus boosting the realization of cleaner production of tanning agent-free leather making.

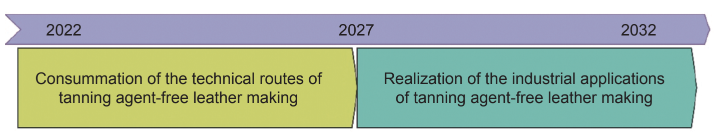


Figure 1.2.7 Roadmap of the engineering research front of “research on the cleaner production technology of tanning agent-free leather making”

Polar organic solvents have the capabilities to provide efficient dehydration role, which are able to be applied in reducing the water content of raw hide effectively. However, the water distribution between organic solvent and raw hide will gradually reach a balance along with the dehydration to proceed, which requires multiple organic solvent changes to achieve deep dehydration performance, thus resulting some problems such as excessive consumption of organic solvents, complicated dehydration process and difficulty in recycling of waste solvents. To this end, the composite dehydration media composed of porous materials and polar organic solvents was developed for realizing the one-step controllable deep dehydration. The porous materials are capable of selectively adsorbing and storing the captured water in the organic solvents, thereby breaking the distribution balance of water between the organic solvent and raw hide so as to keep a constant low water content during the whole dehydration process for realizing continuous dehydration of raw hide. Moreover, the used composite dehydration media were facilely recycled through the solid-liquid separation and reused for tanning agent-free leather making after regeneration. In the future, it is essential to further develop novel composite dehydration media to strengthen the controllable deep dehydration performance of raw hides and consummate the technical routes of tanning agent-free leather making, which in turn lays the foundation for the industrial application of cleaner production technology of tanning agent-free leather making so as to promote the sustainable and green development of the leather industry.

Through the interpretations of core papers on “research on the cleaner production technology of tanning agent-free leather making”, it was found that the citation per paper was relatively low as 5.42 times since this engineering front is still in the early research stage (Table 1.1.1). Table 1.2.9 shows the countries with the greatest output of core papers on this research fronts. Among them, China ranks first with a core paper percentage of 70.83% and a citation of 114 times, which indicates that many Chinese experts and scholars are committed to this front of research. In addition, China also leads other countries and regions in the citations per paper. India ranks second in the two indicators of core paper ratio and citations per paper. In terms of the major output countries or regional cooperation networks (Figure 1.2.8), China and Brazil displayed strong independent research and development capabilities in this field, and many countries also have cooperated extensively.

As shown in Table 1.2.10, the top eight output institutions are all from China, which further indicates that Chinese researchers are highly enthusiastic about this research front. Among them, the top institutions in terms of the percentage of core paper and citation per paper are all Sichuan University, reflecting the leading role of this institution in the engineering front of “research on the cleaner production technology of tanning agent-free leather making”. According to the main inter-agency cooperation network (Figure 1.2.9), most of the institutions have worked in cooperation with other institutions, and a small number of institutions mainly rely on the independent research and development.

As for the ranking of citing papers of this research front, China still occupies a leading position in the world with 54.17% (Table 1.2.11). In addition, the number of citing core papers of Sichuan University and Shaanxi University of Science and Technology leads other scientific research institutions (Table 1.2.12).

Overall, China is not only ahead of other countries in the world, but also has strong independent research and development capabilities in the engineering research front on “research on the cleaner production technology of

Table 1.2.9 Countries with the greatest output of core papers on “research on the cleaner production technology of tanning agent-free leather making”

No.	Country	Core papers	Percentage of core papers/%	Citations	Citations per paper	Mean year
1	China	17	70.83	114	6.71	2019.6
2	India	4	16.67	15	3.75	2020.0
3	USA	2	8.33	1	0.50	2019.5
4	UK	1	4.17	0	0.00	2021.0
5	Brazil	1	4.17	0	0.00	2021.0
6	Ethiopia	1	4.17	0	0.00	2021.0
7	South Sudan	1	4.17	0	0.00	2021.0

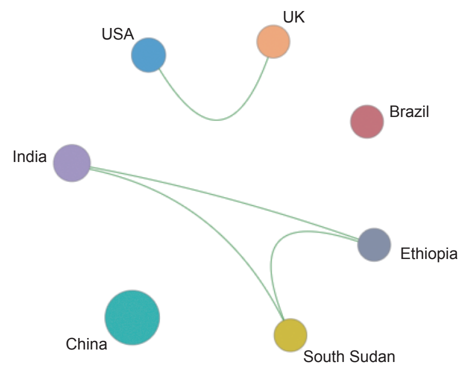


Figure 1.2.8 Collaboration network among major countries or regions in the engineering research front of “research on the cleaner production technology of tanning agent-free leather making”

Table 1.2.10 Institutions with the greatest output of core papers on “research on the cleaner production technology of tanning agent-free leather making”

No.	Institution	Core papers	Percentage of core papers/%	Citations	Citations per paper	Mean year
1	Sichuan University	10	45.45	79	7.90	2019.4
2	Shaanxi University of Science & Technology	4	18.18	22	5.50	2019.7
3	Southwest Minzu University	2	9.09	12	6.00	2020.0
4	Jiaxing University	2	9.09	1	0.50	2019.5
5	Chinese Academy of Sciences	1	4.54	12	12.00	2019.0
6	China National Light Industry Council	1	4.54	6	6.00	2019.0
7	China Leather & Footwear Reseach Institute Co., Ltd.	1	4.54	2	2.00	2020.0
8	Xi'an Key Laboratory of Green Chemicals and Functional Materials	1	4.54	1	1.00	2021.0

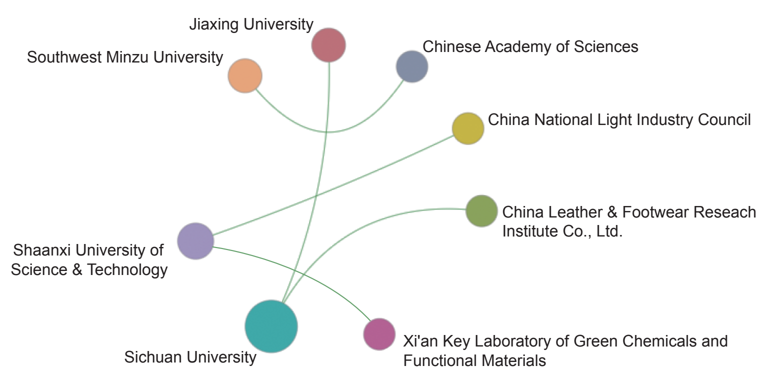


Figure 1.2.9 Collaboration network among major institutions in the engineering research front of “research on the cleaner production technology of tanning agent-free leather making”

Table 1.2.11 Countries with the greatest output of citing papers on “research on the cleaner production technology of tanning agent-free leather making”

No.	Country	Citing papers	Percentage of citing papers/%	Mean year
1	China	26	54.17	2020.2
2	India	7	14.58	2020.4
3	Italy	4	8.33	2020.2
4	Brazil	2	4.17	2020.0
5	Turkey	2	4.17	2020.0
6	Romania	2	4.17	2019.5
7	Tanzania	1	2.08	2020.0
8	South Africa	1	2.08	2020.0
9	South Korea	1	2.08	2020.0
10	Malaysia	1	2.08	2021.0

Table 1.2.12 Institutions with the greatest output of citing papers on “research on the cleaner production technology of tanning agent-free leather making”

No.	Institution	Citing papers	Percentage of citing papers/%	Mean year
1	Sichuan University	14	41.18	2020.1
2	Shaanxi University of Science & Technology	7	20.59	2020.4
3	China Leather & Footwear Reseach Institute Co., Ltd.	2	5.88	2020.0
4	Ca' Foscari University of Venice	2	5.88	2020.0
5	Egerton University	2	5.88	2020.0
6	Babasaheb Bhimrao Ambedkar Bihar University	1	2.94	2020.0
7	University of Lucknow	1	2.94	2020.0
8	Huaqiao University	1	2.94	2020.0

tanning agent-free leather making”. It is recommended that the research institutions should continue to carry out in-depth research in related fields so as to maintain the research status of this research front, and promote the technological development of related industries around the world.

2 Engineering development fronts

2.1 Trends in 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 2016 and 2021 is presented in Table 2.1.2.

(1) Collaborative control technology of high-quality recycling of solid waste and pollution and carbon reduction

The collaborative control technology of high-quality recycling of solid waste and pollution and carbon reduction is the key to realize green recycling and low-carbon development. There is an urgent need to: develop green alternative materials, improve the production process, and reduce the output of solid waste sources; research and develop multi-dimensional green, low-carbon and high-value utilization technologies for solid waste in key industries, taking into account the risk prevention and control of carbon emission reduction and

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	Collaborative control technology of high-quality recycling of solid waste and pollution and carbon reduction	905	2 163	2.39	2018.4
2	Technologies for collaborative control of multi-medium pollution across surface water/groundwater and soil	844	1 465	1.74	2018.8
3	Technology and equipment for cooperative disposal of soil and groundwater in polluted site of industrial gathering area	121	229	1.89	2019.2
4	Ecological control techniques and devices for water quality in rivers and lakes	840	1 093	1.30	2018.5
5	Development of complex land surface models and their applications in Earth System Modeling	852	2 878	3.38	2018.6
6	Research and development of climate models based on machine learning	994	4 481	4.51	2020.2
7	Microwave remote sensing inversion technology of marine 3D dynamic environment	441	1 065	2.41	2019.7
8	Recyclability and reusability of personal protective equipment	994	712	0.72	2019.8
9	Food safety early warning research based on big data and intelligent identification	982	3 337	3.40	2019.6
10	Environmentally friendly pulp molding technology	847	1 065	1.26	2018.8

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	2016	2017	2018	2019	2020	2021
1	Collaborative control technology of high-quality recycling of solid waste and pollution and carbon reduction	137	142	181	203	182	60
2	Technologies for collaborative control of multi-medium pollution across surface water/groundwater and soil	85	116	157	149	188	149
3	Technology and equipment for cooperative disposal of soil and groundwater in polluted site of industrial gathering area	14	7	20	17	31	32
4	Ecological control techniques and devices for water quality in rivers and lakes	101	129	219	131	149	111
5	Development of complex land surface models and their applications in Earth System Modeling	118	130	173	134	128	169
6	Research and development of climate models based on machine learning	3	7	48	131	344	461
7	Microwave remote sensing inversion technology of marine 3D dynamic environment	0	48	53	82	68	190
8	Recyclability and reusability of personal protective equipment	31	50	89	154	247	423
9	Food safety early warning research based on big data and intelligent identification	60	71	120	134	194	403
10	Environmentally friendly pulp molding technology	107	128	152	109	161	190

secondary pollution in the whole life cycle; develop low-energy end treatment process to further reduce carbon emissions. We will focus on the development of cleaner production processes in industrial production, deepen innovation, research and development and application of green, non-toxic and low-carbon alternative new materials, research and development of clean energy alternative technologies, energy cascade utilization technologies, waste green recycling and high-value utilization technologies, and Research on risk assessment and risk prevention and control systems of new pollutants, so as to achieve coordinated control of high-quality recycling of solid wastes and pollution and carbon reduction, Effectively support the green, low-carbon and sustainable development of the social economy.

(2) Technologies for collaborative control of multi-medium pollution across surface water/groundwater and soil

The integrated protection and reclamation of mountains, rivers, forests, farmlands, lakes, grasses and sand is an inevitable requirement to improve the quality and stability of the ecosystem, to promote the harmonious compatibility between human and nature, and to forward ecological civilization construction in the new era. The substance exchange among surface water, groundwater and soil is pronounced, and the mutual replenishment between surface water and groundwater plays an important role in maintaining their healthy states. Therefore, it is urgent to develop technologies for collaborative control of multi-medium pollution across surface water/groundwater and soil. This development frontier contains three main technological directions: ① materials/reagents and biological agents for pollution control and remediation, including zero valent metal nanomaterials exemplified by zero valent iron, layered double hydroxides, biochar, biodegradable polymers, remediation plants, bacterial agents, enzymes, etc., ② pollution control methods and processes, including chemical oxidation and advanced oxidation processes, chemical reduction processes, adsorption, thermal desorption and adsorption/condensation treatment, etc., and ③ pollution control and remediation devices and equipment, including high-pressure injection device, permeable reaction barriers, in-situ oil leakage detection and alarm device, vacuum pumping device and equipment for treating volatile organic compounds, extraction/rinsing device, portable integrated equipment for water treatment, etc. The main target pollutants of the collaborative control technologies include petroleum hydrocarbons, halogenated hydrocarbons, and heavy metals.

The top three countries in terms of the number of the core patent applications in this development fronts are China (65.4%), the USA (13.8%) and South Korea (6.1%), demonstrating the great interests of the patent applicants in such countries to develop the collaborative control technologies for multi-medium pollution. However, practical technologies applicable to surface water pollution control or remediation are still in great demand. A promising field of research in the future is the development of efficient collaborative pollution control technologies based on the multi-medium interaction process and mechanism of composite pollutants across surface water, groundwater, and soil.

(3) Technology and equipment for cooperative disposal of soil and groundwater in polluted site of industrial gathering area

Soil as an important resource, could support the survival and development of human beings, is also the source and sink of large numbers of pollutants. According to the Bulletin of the *National Soil Pollution Survey in 2014*, including 6.3 million square kilometers was under investigation, with a total rate of 16.1 percent exceeding the standard. The main causes of soil pollution are man-made activities such as industry, mining and agriculture. As a typical area with strong human activities, industrial cluster has high urbanization and land utilization rate, always encountering land shortage. There are more than 22 000 industrial zones in China, and 29.4% of the industrial zones have soil exceeding standard. What's more, there are more than 500 000 industrial and mining enterprises retired contaminated sites. As the abundant surface water, shallow underground water level, and sometimes the inshore tidal effect, soil, surface water, and groundwater in industrial cluster always become the sources and sinks of all kinds of pollutants, result in the serious, compound, multi-source, agglomeration shall, and large area pollution, which needs regional coordination control. Most of the existing pollution remediation methods are for a single medium, and are mainly based on a single technology, ecological remediation technology is lacking. It is urgent to study the collaborative treatment technology and equipment of soil and groundwater pollution in industrial clusters, based on the principle of multi-medium process regulation. Integration of pollutant source control scheme to reduce emissions, physicochemical and biochemical methods which strengthen pollutants degradation, purification and catalytic conversion green resource, advanced processing technology such as artificial wetland, creating integration of soil and groundwater remediation equipment, thus to realize the collaborative management and integration of soil water pollution governance mode in industry clusters.

(4) Ecological control techniques and devices for water quality in rivers and lakes

With the development of social economy and the acceleration of urbanization and industrialization, and the sewage discharged into rivers and lakes indirectly or directly is increasing, which reduces the self-purification capacity of rivers and lakes, and the water environment problems such as water bloom, poor quality, black and smelly water are prominent. In order to solve these problems, improve water quality and protect the ecological functions of water bodies, various purification and treatment technologies and equipment have emerged as required. However, the early technical methods are mainly physical and chemical methods, and less attention is paid to the ecological environment of river and lake basins. In recent years, with the continuous improvement of the understanding of ecological environment protection, especially under the promotion of China's government led water ecological protection policy and pollution control action plan, the research on ecological control of water quality in rivers and lakes has ushered in a breakthrough development opportunity, and the relevant technical equipment has become a research and development hotspot. The ecological treatment of water quality mainly includes technologies such as composite ecological filter bed, biofilm purification, biological oxidation of sediment, and biodiversity regulation. The principle is to introduce domesticated aquatic plants, plankton or microorganisms on artificial wetlands or fixed carriers in water, and use their absorption and degradation of pollutants to achieve the purpose of water quality purification. Generally speaking, the operation and maintenance cost of the relevant technical equipment is low, the energy consumption is low, and the stability is long-term. It can significantly improve the self-purification capacity of rivers and lakes and maintain the balance of river and lake ecosystems.

(5) Development of complex land surface models and their applications in Earth System Modeling

The land surface is an important part of the weather-climate-earth system, and its physical, chemical, and biological processes have a profound impact on the exchange of energy and matter between the land and the atmosphere, and between the land and the ocean. Land surface processes refer to all physical, chemical, and biological processes occurring on the land surface, as well as their interactions with the atmosphere and ocean. Land surface process model is a mathematical and physical model that quantitatively describes these processes and studies the interaction between human activities and the environment. It can be simulated by computer. It is the core component of numerical weather/climate/Earth system models. At present, the research of land surface process model used in numerical weather/climate/earth system model needs to emphasize the development of multi-temporal and spatial scale and system integration, the combination of global and regional, macro and micro, ecosystem processes, and the combination of multi-source observation and data assimilation; special emphasis is also placed on the close integration of disciplinary research with national needs, sustainable economic and social development, and policy decision-making, so that the research on land surface process models continues to develop in depth and breadth. Realize the coupling of the newly developed land surface process model and the Earth system model to accurately describe and predict the impact of climate change and human activities on land surface physical, biological, and geochemical processes, providing strong scientific support for weather/climate prediction, water resources security, disaster prevention, food security, ecosystem services and other issues.

(6) Research and development of climate models based on machine learning

Traditional climate models are mainly physical models, and physical models (theory-driven) and machine learning (data-driven) are generally considered as two different scientific research paradigms. But in fact, these two approaches are complementary, that is, physical models can in principle be directly interpretable and have predictive and extrapolation capabilities that do not depend on observational data; while machine learning is highly flexible in exploring data, and may find unexpected patterns from the data. The synergy between the two has attracted more and more attention. The National Center for Atmospheric Research (NCAR) and the National Oceanic and Atmospheric Administration (NOAA) has begun to replace some climate and weather models with machine learning and deep learning models. Traditionally, climate models are largely based on atmospheric and oceanic physicochemical processes, as well as land surface processes. However, they cannot cover the processes that occur on the millimeter or smaller scale in the atmosphere, so these models need to contain some empirical formulations, i.e. parameterizations. Parameterizations can represent complex processes such as clouds and atmospheric convection. An example is strong convection, which occurs on small scales, making it difficult for climate models to accurately represent it. One direction that has attracted attention in recent years is the use of machine learning to more accurately represent small-scale changes in the atmosphere and ocean. That is, firstly, an expensive high-resolution model is run to solve the corresponding process (such as shallow clouds), then machine learning is used to learn from these simulations, and then the machine learning algorithm is incorporated into the climate model to finally form a faster and more accurate climate model.

(7) Microwave remote sensing inversion technology of marine 3D dynamic environment

Microwave remote sensing inversion technology is a technique to infer the remote sensing image characteristics generated by the microwave signals transmitted or reflected by various geographical ground objects received by the sensor, and to infer the electromagnetic wave condition. In other words, remote sensing data can be transformed into various surface characteristic parameters that people actually need.

The essence of remote sensing is inversion, and from the mathematical source of inversion, the inversion research aims at mathematical model first. Therefore, the basis of remote sensing inversion is to describe the Relational Model between remote sensing signals or remote sensing data and surface applications. The key technology of microwave remote sensing inversion of marine 3D dynamic environment lies in the comprehensive accurate acquisition of remote sensing data and the combined application of various data on the one hand, and the selection and application of inversion model on the other hand.

In the future research work, it is integrating and developing existing remote sensing theories and inversion methods, developing a comprehensive inversion algorithm for multi-instrument observations, carrying out remote sensing quantitative inversion and estimation of key ocean elements, establishing a platform for comprehensive observation and inversion of ocean and surface parameters, establishing remote sensing quantitative inversion products of key surface elements with long time series and high accuracy that will provide more accurate and reliable satellite remote sensing observation data for the study and application of marine 3D dynamic environment system process

(8) Recyclability and reusability of personal protective equipment

Personal protective equipment (PPE) includes protective clothing, helmets, masks, goggles, etc., intended to protect the wearer from injury or infection. There has been an increase in the global demand for personal protective equipment, such as disposable medical masks and protective clothing, following the outbreak of COVID-19. Disposable medical and health products have caused incalculable environmental pollution. As reported by the Ocean Conservation Organization, approximately 52 billion masks will be manufactured worldwide in 2020, of which at least 1.56 billion will flow into the ocean and will take at least 450 years to degrade. As a result of the degradation process, the ecological environment of the earth will be adversely affected. As an example of estimated damage, taking a mask after wearing it for 4 hours in different environments, there are 1 096 colonies on the outside of the mask on average, and 1 840 colonies inside the mask. Despite the widespread use of disposable masks in our daily lives, there is an increasing amount of waste caused by discarded disposable masks. Therefore, it has become imperative to recycle and reuse personal protective equipment.

(9) Food safety early warning research based on big data and intelligent identification

Big food data and intelligent identification are used throughout the food chain from production, processing, circulation, market to table. The information and data from the supply, production and marketing of food are collected and stored to form a downward traceability from the production source to the consumption terminal and a reverse traceability from the consumption terminal to the production source. The food supply chain information and data system are built to ensure that the entire production and operation activities of food are always under effective monitoring. Meanwhile, the development of characteristic indication mark, alarm and record marking technology will realize the real-time monitoring of dynamic violations in food production, processing and circulation as well as the continuous dynamic recognition and alarm function of the machine generation of human images, so as to build an innovative visualization information service expression method and information data traceability real-time high definition big data visualization supervision system. By collecting and recording big data on ingredient procurement, sterilization records, food additives, waste disposal, food retention samples, and expiration warnings, a food safety warning method based on big data and intelligent identification is proposed to achieve early warning of expiring food or food change information as well as real-time remote region-wide supervision.

(10) Environmentally friendly pulp molding technology

Petroleum-based plastic products are widely used in product packaging and disposable tableware, while their refractory nature brings potential environmental issues. To address this problem, developing environmentally friendly green degradable materials to replace conventional petroleum-based plastic products is one of the important breakthrough points. Pulp molding technology, a three-dimensional papermaking technique, is capable of enabling pulp to form a pulp wet blank of certain shape and size in a specific mold. The obtained pulp wet blank was subsequently manufactured by cold-pressing dehydration, transferring, hot-pressing drying and other processes to form a molding material. The raw materials of pulp molding technology mainly derived from waste paper in paper industry and non-wood native plant fibers. Therefore, pulp molding products have the advantages of raw materials renewability, products degradability and easy reusability, showing great potentials for the promotable application. Since 2020, the "plastic restriction/plastic ban" policy has been gradually implemented in China, and the pulp molding industry will maintain a high-speed development stage for a long period of time. At present, the molding materials based on the pulp molding technology are mainly utilized in the packaging fields of catering, industrial products, agricultural food and medicine, which also show great development prospects in the future. However, with the improvement of packaging requirements, the shortcomings of pulp molding technology have become increasingly prominent, including the relatively backward supporting equipment, lack of automation level, and low product quality, etc. Especially for the high-quality industrial packaging, the usage effect of pulp molding products is influenced by their packaging cushioning performance, whiteness, moisture-proof performance, corrosion resistance and surface smoothness, etc., which puts forward higher requirements for the overall process flow of environmentally friendly pulp molding technology. Hence, the important research directions for the promotion of this technology in the future are how to select raw materials, chemical additives and inorganic fillers as well as efficiently design molds.

2.2 Interpretations for three key engineering development fronts

2.2.1 Collaborative control technology of high-quality recycling of solid waste and pollution and carbon reduction

How to further improve the resource utilization level of industrial solid waste and effectively prevent the environmental risks in the process of toxic and hazardous chemicals management and solid waste disposal and utilization is an important task to improve the environmental governance system and governance capacity of solid waste and chemicals. The research and development of solid waste disposal technology will be based on the basic principles of reduction, recycling and harmlessness, and will be transformed into the research on the establishment of risk control technology and regulatory system for the whole industry and the whole process. The disposal mode will be transformed from single fight to regional industrial coordination. Green comprehensive utilization, high-value utilization and pollution and carbon reduction coordination will become the key research and development directions in the future. The main development trend forecast in the next 5–10 years is shown in Figure 2.2.1.

First, carry out research on reduction and comprehensive treatment technologies for industrial pollution sources and new pollution sources. Focusing on key industries such as iron and steel, nonferrous metals, building materials, petrochemical, chemical industry and paper making, we will

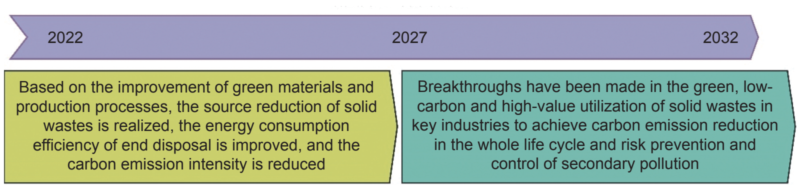


Figure 2.2.1 Roadmap of the engineering development front of "collaborative control technology of high-quality recycling of solid waste and pollution and carbon reduction"

carry out research on key technologies for pollution reduction and carbon source control. Research and develop new low toxicity and low pollution green materials, develop energy efficient combustion technology, clean energy substitution technology, high-temperature flue gas, waste heat and waste water and other energy cascade utilization technologies, waste in-situ regeneration and high-value multi-channel green utilization technologies, and help realize the production process of key industrial enterprises and industrial parks under the low-carbon background through the collaborative control of pollution and carbon reduction sources Reduce the source of emerging solid wastes and high-risk hazardous wastes, prevent the transfer of pollutants across media, reduce the environmental and health risks of new pollutants, and relieve the pressure of comprehensive treatment at the end.

Second, research and develop key technologies for collaborative control of pollution and carbon sources in key industries. In view of the problems such as heavy end treatment load, high cost and lack of effective treatment measures for some pollutants, we will focus on key industries such as iron and steel, nonferrous metals, building materials, petrochemical, chemical industry and papermaking, carry out research and development and integration of key materials and major equipment technologies for pollution and carbon reduction source control, develop new low toxicity, low pollution and low energy consumption materials, clean energy substitution and traditional energy efficient combustion technology, clean production process optimization Key technologies for collaborative control of pollution and carbon reduction sources, such as in-situ regeneration and efficient utilization of wastes in the production process, cascade utilization of energy in the production line such as high-temperature flue gas and waste heat and wastewater, are realized to realize technological innovation of collaborative control of pollution and carbon reduction sources that integrates pollution and carbon reduction, and has multiple objectives such as environmental benefits, economic benefits and climate benefits.

Third, research and development of key technologies for collaborative control of pollution and carbon reduction in industrial parks. Research and develop the key technologies for the efficient recycling of resources in the construction of the ecological industrial chain network of the industrial park; research on the key technologies of green, low-carbon and cascade utilization of energy in industrial parks; research and development of intelligent tracking, identification and optimization control technology for efficient utilization of resources and energy in industrial parks; research on carbon flux monitoring, accounting and carbon Traceability Technology in industrial parks; Research and develop the evaluation technology for the synergy degree of pollution reduction and carbon reduction in the park.

According to Table 2.2.1, the main output countries of core patents in the research direction are China, the USA, Japan and South Korea. Among them, the number of core patents in

Table 2.2.1 Countries with the greatest output of core patents on “collaborative control technology of high-quality recycling of solid waste and pollution and carbon reduction”

No.	Country	Published patents	Percentage of published patents/%	Citations	Percentage of citations/%	Citations per patent
1	China	754	83.31	1 561	72.17	2.07
2	USA	32	3.54	182	8.41	5.69
3	Japan	27	2.98	92	4.25	3.41
4	South Korea	18	1.99	30	1.39	1.67
5	Germany	10	1.10	34	1.57	3.40
6	France	10	1.10	34	1.57	3.40
7	Belgium	7	0.77	20	0.92	2.86
8	Canada	6	0.66	67	3.10	11.17
9	Russia	6	0.66	17	0.79	2.83
10	Italy	6	0.66	15	0.69	2.50

China ranks first, accounting for 83.31%, exceeding 80% of the global patents. The USA followed, accounting for 3.54%. The cited number of Chinese patents is 72.17%, ranking the first in the world. Countries mainly conduct research independently. There is no cooperation among major countries.

It can be seen from Table 2.2.2 that the institutions with a large number of core patents in this research direction are Central South University, Institute of Process Engineering, Chinese Academy of Sciences, Foshan Sanshui Xiongying Aluminium Surfacing Technology Innovative Centre Company Limited, Jiangsu Province Metallurgical Design Institute Company Limited, Jiangsu University of Technology, and Pangang Group. The number of core patents of these institutions exceeds 6. Institutions mainly conduct research independently. There is no cooperation among major institutions.

According to the above data analysis results, China's core patent output and the number of core patents introduced in the field of Collaborative control technology of high-quality recycling of solid waste and pollution and carbon reduction are among the world's leading, and the number of core patents introduced by Chinese research institutions is relatively large.

2.2.2 Development of complex land surface models and their applications in Earth System Modeling

The land-atmosphere and land-sea interfaces are the main places for human activities. With the development of human society, the changes of the earth's land surface caused by human activities have profoundly affected the exchange of matter and energy between land-air and land-sea, and the changes of regional climate and ecological environment. These changes have had a huge impact on nature and humans. Accurately describing the physical, chemical and biological processes of the land surface, accurately calculating the state of the land surface and the material and energy exchange fluxes at the land-atmosphere and land-sea interfaces, is of great scientific and social significance to numerical forecasting of weather/climate, to fully understand the formation mechanism of water security, food security, ecological environment deterioration and other problems caused by global change, and to formulate corresponding countermeasures.

The development of land surface process models has mainly experienced four stages so far, from the relatively simple "bucket model" and the simple energy balance model to the fourth generation of land surface process models containing

Table 2.2.2 Institutions with the greatest output of core patents on "collaborative control technology of high-quality recycling of solid waste and pollution and carbon reduction"

No.	Institution	Published patents	Percentage of published patents/%	Citations	Percentage of citations/%	Citations per patent
1	Central South University	27	2.98	84	3.88	3.11
2	Institute of Process Engineering, Chinese Academy of Sciences	9	0.99	33	1.53	3.67
3	Foshan Sanshui Xiongying Aluminium Surfacing Technology Innovative Centre Company Limited	9	0.99	2	0.09	0.22
4	Jiangsu Province Metallurgical Design Institute Company Limited	7	0.77	16	0.74	2.29
5	Jiangsu University of Technology	7	0.77	11	0.51	1.57
6	Pangang Group	7	0.77	6	0.28	0.86
7	Nantong Jiuzhou Environmental Protection Technology Company Limited	6	0.66	3	0.14	0.50
8	Hunan Xinhuochuan Environmental Protection Technology Company Limited	6	0.66	2	0.09	0.33
9	China Petroleum & Chemical Corporation	5	0.55	42	1.94	8.40
10	Changsha Zichen Technology Development Company Limited	5	0.55	16	0.74	3.20

the refined descriptions of land surface physics, chemistry and biology, which has greatly improved our understanding of the land-surface systems. However, the description of the impact of human activities on land surface process disturbances in existing models is relatively lacking or too simple. It is the main goal of future land surface model research and development to include the human activities and ecosystem processes, to realize high-resolution simulation, and to further realize the coupling between the new land surface process model and the earth system model to accurately describe and predict the impact of climate change and human activities on land surface physical, biological and geochemical processes.

The main countries with the greatest output of core patents on "development of complex land surface models and their applications in Earth System Modeling" are shown in Table 2.2.3. China ranked first in the number of core patent disclosure, the USA ranked second, and France third. However, the average number of citations is lower than that of the USA. This indicates that although China has many core patents in this field, the patents lack of innovation and influence. The technical level of our country in this field still needs to be improved. From the collaboration network between the frontier countries on "development of complex land surface models and their applications in Earth System Modeling" (Figure 2.2.2), it can be seen that the USA, France, Netherland and Canada have collaborations with others, while China has

Table 2.2.3 Countries with the greatest output of core patents on "development of complex land surface models and their applications in Earth System Modeling"

No.	Country	Published patents	Percentage of published patents/%	Citations	Percentage of citations/%	Citations per patent
1	China	668	78.40	1 283	44.58	1.92
2	USA	112	13.15	643	22.34	5.74
3	France	19	2.23	87	3.02	4.58
4	Saudi Arabian	19	2.23	73	2.54	3.84
5	South Korea	15	1.76	10	0.35	0.67
6	Netherlands	14	1.64	50	1.74	3.57
7	Canada	13	1.53	37	1.29	2.85
8	Luxembourg	12	1.41	68	2.36	5.67
9	Japan	11	1.29	4	0.14	0.36
10	UK	8	0.94	21	0.73	2.62

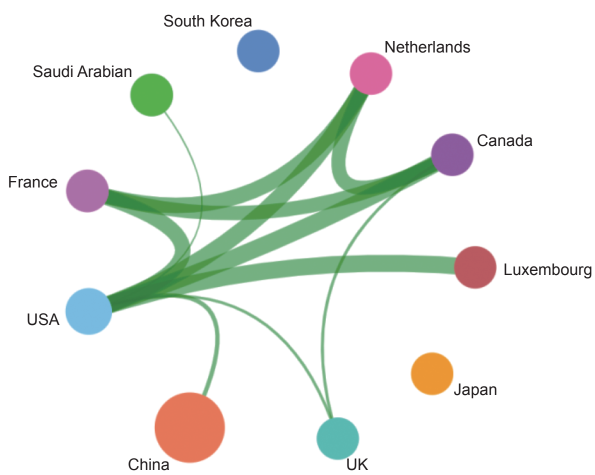


Figure 2.2.2 Collaboration network among major countries in the engineering development front of "development of complex land surface models and their applications in Earth System Modeling"

little collaboration with other countries except the USA.

The main institutions with the greatest output of core patents on “development of complex land surface models and their applications in Earth System Modeling” are shown in Table 2.2.4. The top two cited institutions are SAOC (19) and HESI (19), which are from the Saudi Arabian and the USA institutions. From the perspective of published patents, five of the top ten institutions are from China. Figure 2.2.3 presents the collaboration network among various institutions of the development frontier. As shown in the figure, the collaboration relationship between the development frontier among various institutions or enterprises is very weak and only Paradigm Sciences Limited and Emerson Paradigm Holding Limited Liability Company has collaborations. This indicates that we should further strengthen exchanges and collaboration with other countries and institutions to further enhance China’s innovation capabilities in this field.

Figure 2.2.4 shows the roadmap of the engineering development front of “development of complex Land surface models and their applications in Earth System Modeling”. It can be seen that there are two key development stages that this development front will experience in the next 5–10 years. The first is to introduce human activities and ecosystem processes into the land surface model. On this basis, the

Table 2.2.4 Institutions with the greatest output of core patents on “development of complex land surface models and their applications in Earth System Modeling”

No.	Institution	Published patents	Percentage of published patents/%	Citations	Percentage of citations	Citations per patent
1	Saudi Arabian Oil Company (SAOC)	19	2.23	73	2.54	3.84
2	Halliburton Energy Services Incorporation (HESI)	19	2.23	60	2.08	3.16
3	China Institute of Water Resources and Hydropower Research	16	1.88	71	2.47	4.44
4	Schlumberger Limited	14	1.64	43	1.49	3.07
5	Paradigm Sciences Limited	11	1.29	82	2.85	7.45
6	Institute of Agricultural Resources and Regional Planning Chinese Academy of Agricultural Sciences	11	1.29	21	0.73	1.91
7	Emerson Paradigm Holding Limited Liability Company	10	1.17	28	0.97	2.80
8	China Petroleum & Chemical Corporation	10	1.17	23	0.80	2.30
9	State Grid Corporation of China	10	1.17	12	0.42	1.20
10	China University of Mining & Technology Beijing	9	1.06	23	0.80	2.56

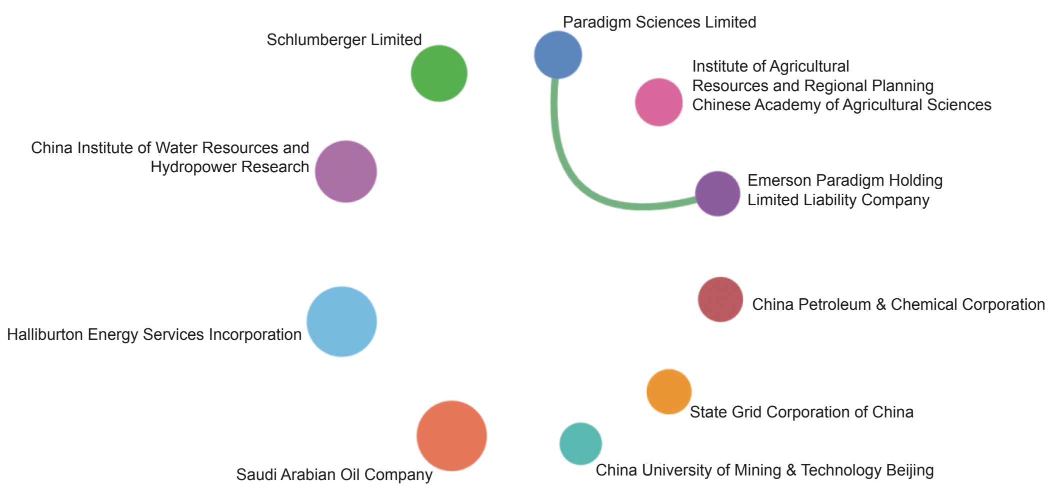


Figure 2.2.3 Collaboration network among major institutions in the engineering development front of “development of complex land surface models and their applications in Earth System Modeling”

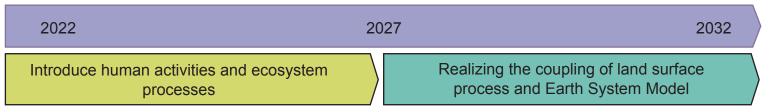


Figure 2.2.4 Roadmap of the engineering development front of "development of complex land surface models and their applications in Earth System Modeling"

second stage goal is to achieve the couple of land surface process models with earth system models.

2.2.3 Recyclability and reusability of personal protective equipment

With the sudden global outbreak of the new crown pneumonia epidemic, it has become necessary to recycle and upgrade discarded personal protective equipment, especially disposable medical masks, in light of the new situation at home and abroad. For example, disposable medical masks typically consist of two layers of spunbond nonwoven material combined with a layer of meltblown nonwoven material as the main body, with ear straps and nose clips attached. Raw material for the main part of the product is polypropylene (PP). It is the primary function of spunbond nonwoven fabrics to provide waterproof and anti-sputtering properties, as well as to provide a certain level of strength to prevent melt-blown nonwovens from becoming weak in the inner layer. The melt-blown non-woven material in the middle layer serves primarily as a filter. The melt-blown nonwoven material has a small fiber diameter, approximately 2 μm, a small pore size, and a large porosity. As a result of electrostatic evaporation, the composite mask is able to effectively absorb dust particles as well as capture bacteria and virus droplets.

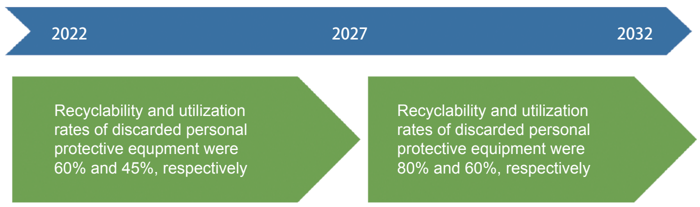
Currently, discarded disposable medical masks can be recycled and processed utilizing four different methods: landfilling, incineration, physical recycling, and chemical recycling. In landfills, masks are decomposed by microorganisms, taking a long time to degrade and polluting the soil as a result. Incineration uses the heat generated by combustion to generate power and drive mechanical devices. This process is mature and simple, and it has a wide range of applications, but it is associated with serious environmental pollution, a low capacity for production, and low resource utilization. The discarded disposable medical masks are broken into specified sizes, mixed with other materials evenly, and adhered to form a new product under the influence of heat, pressure, or a combination of both. Among the characteristics of the process are its relative maturity and its simplicity. There is a low utilization rate of resources; chemical recycling is more effective in repurposing waste disposable medical masks. Through chemical reactions, polymer macromolecules are converted into small molecular compounds for further utilization, or specific groups in waste masks react with chemical reagents to create new ones. In addition to its high added value, this product also protects the environment with green reagents, but some of its reagents pollute the environment, so they can be replaced with green reagents that are environmentally friendly.

Essentially, forming national awareness about the classification and treatment of discarded masks is the basis for developing a new selective green catalyst, degradant, and collaborative detection technologies on the basis of exploring the mechanism of decomposition, reconstruction and re-functionalization of mask-related materials. The formulation of new mask standards, the development of new ideas for utilizing the residual value of existing disposable medical masks, and the development of next generation chemically recyclable mask materials will greatly facilitate the upgrading and reconstruction of discarded disposable medical masks, contributing to society's sustainable development by transforming waste into treasure.

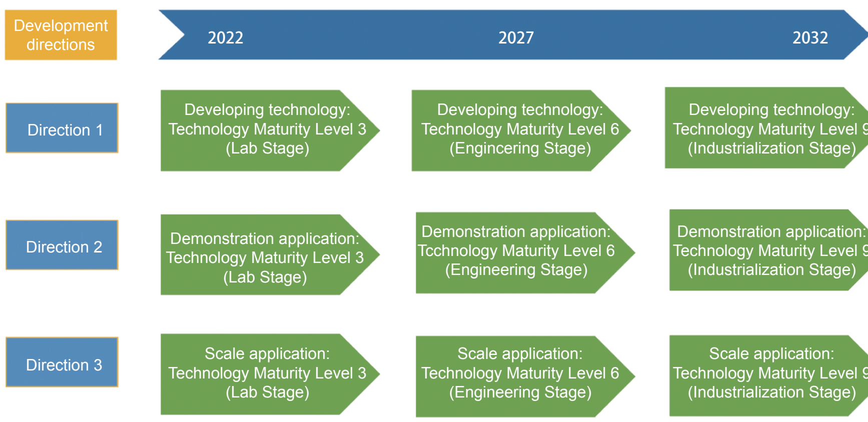
Figure 2.2.5 illustrates the roadmap of engineering development front of "recyclability and reusability of personal protective equipment".

In the context of normalized prevention and control needs in the post-epidemic era, it is necessary for my country to improve the prevention and control system for major epidemics in order to compensate for the shortcomings of my country's medical waste disposal capacity and establish a sound emergency response mechanism which will provide important support for the barrier. Innovative development is necessary in order to recycle medical waste. China has made significant research investments in the development of waste textile recycling in recent years, and the recycling technology for personal protective equipment is continuously being developed. According to Table 2.2.5, China has disclosed up to 974 patents in recent years, representing 97.99% of all disclosed patents, followed by the USA and South Korea, each with five disclosures. Compared to the USA, Russia, and Japan, China has a much higher number of patents for recycling and reuse of personal protective equipment.

Compared to the USA, Russia, and Japan, Chinese patents have a much lower average citation frequency (Table 2.2.5). There is still a lack of innovation and originality in the recycling of personal protective equipment. Insufficient and insufficient influence; among the top 10 institutions producing core patents (Table 2.2.6), the top two institutions are Shunchihua (Qingdao) Intelligent Technology Co., Ltd. and Bosi Yingnuo Technology (Beijing) Co., Ltd. There is no R&D cooperation among the major countries and institutions in this development front, and the degree of industrialization is low. There is still a lot of room for industry-academia-research cooperation on recycling technology for personal protective equipment. To further enhance our country's innovation capabilities, we need to strengthen exchanges



(a) Indicators of key performance



(b) Description of development maturity

Figure 2.2.5 Roadmap of the engineering development front of "recyclability and reusability of personal protective equipment"

Table 2.2.5 Countries with the greatest output of core patents on "recyclability and reusability of personal protective equipment"

No.	Country	Published patents	Percentage of published patents/%	Citations	Percentage of citations/%	Citations per patent
1	China	974	97.99	610	85.67	0.63
2	USA	5	0.50	79	11.10	15.80
3	South Korea	5	0.50	3	0.42	0.60
4	Russia	4	0.40	11	1.54	2.75
5	Japan	3	0.30	8	1.12	2.67
6	Poland	1	0.10	1	0.14	1.00
7	UK	1	0.10	0	0.00	0.00

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

Table 2.2.6 Institutions with the greatest output of core patents on "recyclability and reusability of personal protective equipment"

No.	Institution	Published patents	Percentage of published patents/%	Citations	Percentage of citations/%	Citations per patent
1	Shunchihua (Qingdao) Intelligent Technology Co., Ltd.	6	0.60	0	0.00	0.00
2	Bosi Yingnuo Technology (Beijing) Co., Ltd.	4	0.40	4	0.56	1.00
3	Anhui Kunjian Biotechnology Co., Ltd.	3	0.30	2	0.28	0.67
4	China State Railway Group Co., Ltd.	3	0.30	1	0.14	0.33
5	Shaoxing Xucheng Environmental Protection Equipment Co., Ltd.	3	0.30	1	0.14	0.33
6	Hengyang Wangfa Tin Co., Ltd.	3	0.30	0	0.00	0.00
7	EcoATM Incorporation	2	0.20	76	10.67	38.00
8	China Shipbuilding Industry Corporation	2	0.20	15	2.11	7.50
9	Shenyang Institute of Automation, Chinese Academy of Sciences	2	0.20	11	1.54	5.50
10	Changsha Pengyue Wuyang Information Technology Co., Ltd.	2	0.20	5	0.70	2.50

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