VI. Environmental and Light Textile Engineering

1 Engineering research fronts

1.1 Trends in top 10 engineering research fronts

The top 10 engineering research fronts in the field of environmental and light textile engineering (hereafter referred to as environmental engineering), which includes the subfields of environmental science engineering, meteorological science engineering, marine science engineering, food science engineering, textile science engineering, and light industry science engineering, are summarized in Table 1.1.1. The annual number of core papers for individual research fronts between 2013 and 2018 are summarized in Table 1.1.2.

(1) Application of nano-composite materials in wastewater treatment

Along with increases in socio-economic development, large amounts of sewage have been discharged into the environment, and this waste has degraded aquatic environments in many areas and is presently posing threats to the ecological environment and human health. Therefore, effective treatment of pollutants in water is an important research topic in the environmental field. Although traditional water treatment methods have achieved certain positive effects in many applications, they also have disadvantages such as high energy consumption, low efficiency, and secondary pollution. With the advancement of science and technology, many new materials have begun to be used in water treatment. Nanomaterials are considered to be good reagents for handling many pollutants because of the superior surface area and active sites of nanomaterials. Nano-photocatalytic technology, nanofiltration membrane technology, nano-reduction technology, and nano-adsorption technology all have shown some success in the field of water treatment. Compared to single-component nanomaterials, nano-composite materials composed of a variety of nanomaterials generally have superior properties. The advantages of each component can be achieved by designing the raw material use, distribution of components, and process conditions accordingly. Therefore, the application of nanocomposites in wastewater treatment potentially will have a huge impact on future environmental protection goals and sustainable development, and it has broad application prospects.

(2) Efficient seawater desalination technology

Desalination of seawater involves the use of seawater desalination technology to produce fresh water. It is a type

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	Application of nano-composite materials in wastewater treatment	69	5 402	78.29	2015.4
2	Efficient seawater desalination technology	43	3 689	85.79	2014.9
3	Effects of soil pollution on crop metabolism	37	2 105	56.89	2014.2
4	Environmental pollution and mitigation of antibiotic resistance genes	32	807	25.22	2016.0
5	Climate change and the ecological environment	1400	303 709	216.94	2014.0
6	Severe smog in winter	192	4 613	24.03	2016.8
7	Monitoring and control of marine microplastic pollution	115	18 840	163.83	2014.6
8	Rapid screening and intelligent identification of harmful chemicals in food	10	514	51.40	2014.8
9	Preparation and application of highly efficient oil–water separation materials	17	1 598	94.00	2015.2
10	Biomass clean energy	130	11 108	85.45	2014.5

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	2013	2014	2015	2016	2017	2018
1	Application of nano-composite materials in wastewater treatment	6	14	17	16	12	4
2	Efficient seawater desalination technology	12	7	8	6	9	1
3	Effects of soil pollution on crop metabolism	14	9	8	4	1	1
4	Environmental pollution and mitigation of antibiotic resistance genes	3	3	4	5	14	3
5	Climate change and the ecological environment	587	391	267	112	34	9
6	Severe smog in winter	4	8	18	32	63	67
7	Monitoring and control of marine microplastic pollution	19	39	32	17	8	0
8	Rapid screening and intelligent identification of harmful chemicals in food	3	2	1	2	2	0
9	Preparation and application of highly efficient oil–water separation materials	0	5	6	4	2	0
10	Biomass clean energy	39	38	22	19	10	2

of open source incremental technology for water resource utilization, which can increase the total amount of fresh water available for use. The development of high-efficiency seawater desalination technology is of great significance for alleviating the shortages of water resources in coastal water-deficient areas and islands, promoting the desalination and utilization of brackish water in inland areas, optimizing the water use structure, and ensuring the sustainable use of water resources. How to improve the efficiency of seawater desalination, reduce energy consumption and costs, and increase the scope of its applications are difficult problems facing researchers working on high-efficiency seawater desalination. Seawater desalination methods currently used include the seawater freezing method, electrodialysis method, distillation method, reverse osmosis method, and ion exchange method. Presently, the reverse osmosis membrane method and distillation method are the most common methods in use. Key technologies such as large-scale thermal membrane desalination and large-scale seawater circulation cooling, as well as key components such as reverse osmosis desalination membrane modules, high-pressure pumps, and energy recovery and thermal seawater desalination core components are hot topics in efficient seawater desalination research. The development of technologies that utilize waste heat from power plants and renewable energy sources such as nuclear, wind, ocean, and solar energy are also the focus of much attention. Actively researching and developing engineering technologies and complete facilities capable of seawater withdrawal, pretreatment, desalination, desalinated water post-treatment, and concentrated brine utilization and disposal represent the future development directions of efficient seawater desalination technology.

(3) Effects of soil pollution on crop metabolism

Soil is the basis of plant growth and development. Soil supplies water, fertilizer, gas, and heat for the normal growth and development of plants. These basic properties affect the growth and development of plants both directly and indirectly. Soil pollution is caused by excessive harmful substances in the soil that exceed the self-purification ability of the soil and change its composition, structure, and function. The effects of soil pollution on crop metabolism mainly occur in the following ways. First, inorganic pollutants such as heavy metals can destroy the normal absorption and metabolic functions of crop roots, which is usually related to the inhibition of enzymes in plants. For example, under Cd stress, the absorption of water and nutrients by crop roots is weakened, the permeability of cell membranes is enhanced, the soluble substances in cells are exuded, and the metabolic activity of intracellular enzymes is hindered. Second, contaminated pollutants can affect the normal physiological functions of crops. For example, trichloroacetaldehyde can destroy the polar structure and components of plant cell protoplasm. Chemically induced functional impairments can lead to alterations in the division of cells and nuclei, the formation of pathological tissues, reductions in normal growth and development, and even plant death. Third, pathogenic microorganisms in soils can enter crops, blocking normal metabolic pathways and causing related diseases such as bacterial and fungal wilt, rot, smut, and root swelling.

(4) Environmental pollution and mitigation of antibiotic resistance genes

Antibiotics enter the environment along with the discharge of municipal wastewater, livestock wastewater, hospital wastewater, pharmaceutical wastewater, etc., and these chemicals can cause environmental pollution problems in aquatic ecosystems and soil. The presence of antibiotics results in selective pressure on environmental bacteria, and this enhances antibiotic resistance and the generation of resistance genes. Antibiotic resistance genes (ARG) have been regarded as an emerging environmental pollutant. The wide spread occurrence and diffusion of ARG may reduce the curative effects of antibiotics and has attracted global attention due to its risk to public health and ecosystems. Wastewater treatment systems that discharge antibiotics and bacteria are the primary source of anthropogenic induced ARG. Conventional wastewater treatment processes have a limited capacity for ARG removal. Current research indicates that activated sludge in the biological treatment units may concentrate more ARG compared with the wastewater, and many bacteria isolated from the wastewater treatment systems show resistance to multiple antibiotics.

The recent hot papers in this field have mainly focused on evaluations of the effects of different wastewater treatment processes (including coagulation/sedimentation, filtration, membrane processes, chlorination, UV irradiation, ozonation, UV/H_2O_2, photocatalysis, photoFenton) on ARG removal. The separation techniques such as precipitation have been shown to reduce the ARG concentration in wastewater via sedimentation of ARG into the sludge but could not eliminate the ARG. However, advanced oxidation processes (AOPs) have significant effects on ARG removal via the destruction of the structure of ARG and thus can reduce the corresponding environmental risks. However, the degree of ARG removal depends strongly on the dose and duration of the AOP. For example, some studies have reported that there is an increase in the resistance level after treatment with low dose chlorination or ultraviolet radiation (UV) processes. Therefore, it is necessary to further investigate the technologies and processes that can remove ARP from source wastewaters such as hospital wastewater, pharmaceutical wastewater, and livestock wastewater. Currently, the ARG relevant studies have mainly focused on soil and water environments, while less attention has been paid to the atmospheric environment. It will be important to enhance such research on the characteristics, spread, transport, and mitigation of ARG in the environment.

(5) Climate change and the ecological environment

Climate change refers to the evolution of climate conditions over long time periods, and the impacts of climate change can be severe. For example, thousands of people die from climate change each year, and the ecological environment is greatly affected. Climate change not only causes the rise of global mean surface temperature and global warming, but also leads to increases in the number and severity of various types of disasters including droughts, sandstorms, floods, heat waves, hurricanes, tropical storms, tornadoes, and wildfires.

In recent years, the impacts of climate change on the ecological environment have attracted the attention of various countries around the world, therefore each country should develop a plan for responding to and adapting to future climate changes, especially in regard to construction activities. For example, research is needed to provide scientific and technological support for the formulation of major national strategic policies, and an assessment framework for new climatic carrying capacities should be established, which considers the characteristics of economic and social development and ecosystem services, with an emphasis on urbanization climate effects, regional air pollution control, watersheds, and protection of vulnerable areas.

China has further considered improving the layout of eco-meteorological observation stations in key eco-functional areas, eco-sensitive areas, and vulnerable areas in different national plans, which could enhance the capacity of meteorological monitoring networks in forests, grasslands, deserts, wetlands, and other eco-regions. Establishment of a comprehensive early warning system for eco-meteorological related disasters and extreme climate events, such as air pollution, soil erosion, droughts, and land desertification would be valuable. Strengthen eco-meteorological assessment and eco-security meteorological support, and promote fine assessment and planning of climate resources.

(6) Severe smog in winter

Smog is a kind of disastrous weather event that occurs in the near-surface layer of the atmosphere. Because of the decreases in atmospheric visibility caused by such haze, these events can have an important impact on socioeconomic activities and people's lives. At the same time, when smog occurs, atmospheric aerosols gather in the near surface layer of the atmosphere, which degrades the air quality and represents an important hazard to human health. Previous studies have shown that the long-term trends of fog and haze are closely related to human activities and climate change. The expansion of cities and the associated heat island effects can actually cause the frequency of fog to decrease in urban areas but increase in suburban areas. The decreasing trend of the frequency of heavy fog in urban areas is related not only to the increasing trend of urban heating, but also to the decreasing trend of suspended particulate matter.

Obvious seasonal and interdecadal variations in the number of fog days in China have been detected, in which most of the events occur in winter and fewer occur in spring, and the overall number was higher in the 1970s to 1990s than the period after the 1990s when the number of events decreased; meanwhile, the number of haze days has increased sharply since 2001. The decreasing trend of foggy days in China is related to the increase of the minimum temperature and decrease of the relative humidity in winter. The increase of haze days is closely related to the increasing trend of atmospheric pollutant emissions caused by human activities and the decreasing trend of average wind speed. In addition, the spatial distribution of the changes of haze in China is closely related to economic activities. In the economically developed eastern and southern parts of China, an increasing trend of haze days has been observed, while in the relatively less developed northeast and northwest regions, a decreasing trend is occurring.

Concerning the relationship between the occurrence of smog and meteorological factors in China, studies have focused on the relationship between the long-term trend of haze and that of meteorological factors, the evolution process of local meteorological conditions and fog generation and disappearance, and the relationship between local meteorological conditions and haze weather. At the same time, in order to prevent the occurrence of smog weather, the state has formulated a variety of control and environmental protection measures, which are intended to reduce the occurrence of haze.

(7) Monitoring and control of marine microplastic pollution

Microplastics pollution is an emerging marine environmental issue that has attracted great concern worldwide. Microplastic particles, which are generally less than 5 mm in diameter, can be detected in almost every marine habitat including those in polar regions. These particles are easily ingested by marine organisms and usually adsorb other chemical pollutants. Hence, microplastics can migrate and be enriched along the food chain and have ecotoxic effects. Standardized monitoring methods for microplastics have been established. Visual detection after density separation and digestion of environmental samples, combined with Fourier transform infrared spectroscopy or Raman spectroscopy, is a widely accepted method for qualitative and quantitative research on microplastics.

Based on standard and reliable detection technology, the source–sink processes and ecological risk mechanisms of microplastics in the ocean are hot scientific issues that are engaging researchers all over the world. In addition, nano-scale microplastics may have more significant physiological and ecological toxicity, and efficient monitoring techniques are still a challenge for such material.

The prevention and control of microplastic pollution is mainly carried out at two levels, namely, legislation in the political realm and technological advances in the scientific and engineering realm. At the regulatory level, measures can be taken such as government regulations mandating the recycling of plastic products and prohibiting the addition of micro-plastic particles to household products such as toothpaste and facial cleansers. Such measures can effectively help to reduce and control plastic emissions. At the technical level, low-cost production of biodegradable plastic products such as polylactic acid can be used to replace a portion of the traditional plastic source stock for products, and plastic products that show little to no degradation can be banned. Moreover, breakthroughs in plastic decomposition technology, such as the use of enzymes and organisms with high plastic degrading activities, to degrade plastic waste is expected to contribute to the environmental remediation of contaminated areas.

(8) Rapid screening and intelligent identification of harmful chemicals in food

There are various kinds of exogenous and endogenous hazards in food. Many food hazards are complex in terms of the chemical structures, and some of these may experience a series of complicated chemical changes during food processing, the products of which are associated with great uncertainties. Therefore, rapid screening and identification of hazardous compounds are of great significance for the effective management of food safety hazards. At present, with the application of novel analytical instruments such as in high-resolution mass spectrometry, and with the developments in information analysis techniques for data detection, there are great technical potentials for continuous innovation in establishing powerful platforms for the rapid-screening of unknown harmful substances.

(9) Preparation and application of highly efficient oil–water separation materials

The continuous discharge of oily industrial wastewater and domestic sewage and the frequent occurrence of marine oil spill accidents have resulted in the formation of a large number of oil–water mixtures, environmental pollution, and economic losses. Thus, the development of oil–water separation technology has important practical significance and application value. The presence of oil contaminants in the water can hinder the exchange of water and air and the normal incidence of sunlight, thus causing fatal damage to aquatic organisms, and the oil contains a large number of mutagenic and carcinogenic hydrocarbon compounds that will pass through the ecosystem. Contaminants ingested in the food chain and eventually enriched in the human body can pose a serious threat to human health. Therefore, this type of water pollution is a global problem that needs to be solved urgently. When oil enters a water body, it will form the following four types of oil–water mixtures: oil slicks, dispersed oil, emulsified oil, and dissolved oil. The oil slicks and dispersed oil can easily coalesce into a continuous oil layer because of the large particle size and be removed by adsorption, sedimentation, and mechanical method. For the separation of relatively stable emulsified oils and dissolved oils, traditional demulsification techniques such as sedimentation, biological methods, ultra/microfiltration membrane separation, etc., are required. While a certain separation effect can be obtained with existing technology, these methods are associated with high rates of energy consumption and low processing efficiencies. At present, oil–water separation technology is a focus of research in all countries around the world. The main research directions in this field focus on the preparation of fiber-based, high-efficiency oil–water separation membranes, the synthesis of new high-efficiency oil–water separation materials, the construction of super-infiltration oil–water separation systems, and the development of ceramic-based/bio-based oil-water separation materials, among other aspects.

(10) Biomass clean energy

The energy demands of human society are continuously growing, but there are limited supplies of fossil energy. At the same time, environmental problems caused by the excessive consumption of fossil energy have become increasingly significant. Therefore, the development of renewable and clean energy has become a primary focus for achieving sustainable development in future human societies. Biomass energy represents the solar energy stored in biomass in the form of chemical energy. As a new type of renewable energy, biomass energy features several desirable properties including rich sources for production, renewability, and low pollution potential and safety compared with traditional fossil energy. The effective utilization of biomass energy cannot only help to meet current energy demands, but also reduce pollutant emissions to the environment. Therefore, biomass energy has great potential for optimizing the structure of the energy supply.

The key to developing biomass energy is figuring out how to take full advantage of biomass energy in a clean and efficient manner. At present, the main components of utilizing biomass energy include 1) biomass power generation, e.g., agricultural and forestry biomass power generation, biogas power generation, and garbage power generation; 2) biomass gas supplies, e.g., biogas, biomass gasification gas; 3) biomass solid fuel, e.g., agricultural and forestry biomass-based molded fuel; 4) biomass liquid fuel, e.g., bioethanol, biodiesel. However, the full utilization of biomass energy faces many challenges. In the future, it will be essential to scale up the utilization of biomass energy in the fields of electricity, heat supply, and transportation, and the further development of new technologies for biomass energy utilization also will be crucial.

1.2 Interpretations for three key engineering research fronts

1.2.1 Application of nano-composite materials in wastewater treatment

Along with increases in socioeconomic development, large amounts of pollutants have been discharged into the environment, which has led to many environmental problems such as air, soil, and water pollution. In particular, large amounts of untreated sewage are directly discharged into the environment in many areas, which has caused severe deterioration in water quality. Presently, there are many kinds of pollutants in water bodies. Common pollutants include heavy metals, bacteria, viruses, radionuclides, and organic dyes. Due to the high toxicity, stability, and refractory characteristics of many pollutants in water, these pollutants pose great threats to the ecological environment and human health. Therefore, how to effectively treat pollutants in water has become an important research topic in the environmental field.

Although conventional water treatment methods such as adsorption techniques, coagulation techniques, and activated sludge techniques have achieved certain positive effects in various applications, they also have disadvantages such as low efficiency, high cost, high energy consumption, and secondary pollution. With the advancement of science and technology, innovations in water treatment technology have not only been limited to the development of traditional treatment technology, and in fact, many new materials also have begun to be applied in water treatment, thus leading to rapid developments in water treatment technology. Nanomaterials are attracting attention because of their superior surface area, active sites, and other advantages, and these are considered to be good reagents for handling many pollutants. Nano-photocatalytic technology, nanofiltration membrane technology, nano-reduction technology, and nano-adsorption technology have achieved certain positive achievements in the field of water treatment.

Compared with single-component nanomaterials, nanocomposites composed of a variety of nanomaterials generally have superior performance in terms of contaminant removal. Nanocomposites may also bring about new properties that are not available with the original components while maintaining the properties of the original components. In addition, the composite material can achieve the complementary advantages of each component and maximize the advantages through the proper design of raw materials, distribution of various components, and process conditions.

With the deepening of nanotechnology research, and people's increasing attention to the environment, nanotechnology and nano-composite materials will likely become more and more widely used for environmental protection, especially in water treatment applications. The application of nanocomposites in wastewater treatment could have a huge impact on future environmental quality and sustainable development, and this technology has broad application prospects.

As shown in Table 1.2.1, China ranks first with 43 core papers, which indicates that many Chinese experts and scholars are committed to this front of research. Although China is still the first in terms of Citations the USA has nearly doubled the number of citations per paper in China, thus indicating that the research results of the USA are among the highest in the world. Among the top 10 countries or regions with the greatest output of core papers, developing countries account for a high proportion, which may reflect the current seriousness of problems related to water pollution in developing countries.

Hunan University ranks first in terms of core papers and citations as shown in Table 1.2.2. In terms of citations per paper, the rankings of the institutions that have been cited more than 100 times are from Central South University, Hunan University, Fuzhou University, and South China University of Technology. These results show that Central South University is at a high level in terms of this research topic.

As shown in Figure 1.2.1, China, the USA, Malaysia, Iran, and Saudi Arabia have shown relatively more cooperation with other countries. China cooperates most closely with the USA, followed by Saudi Arabia.

In general, there has been less cooperation among major institutions as shown in Figure 1.2.2. Hunan University has shown close cooperation with Central South University, Chinese Academy of Sciences, and Yanshan University. South China University of Technology has worked in cooperation with Central South University and Hunan University as well.

According to Table 1.2.3, the citing papers of China is far ahead of other the countries or regions, followed by the USA and India. The mean year of citing papers for the top ten countries is around 2017.

According to Table 1.2.4, Hunan University and Chinese Academy of Sciences have significantly higher citing papers values than the other institutions, and these rank first and second, respectively. The gap between the two institutions is small. The mean year of citing papers for the top ten institutions is around 2017.

Table 1.2.1 Countries or regions with the greatest output of core papers on the "application of nano-composite materials in wastewater treatment"

No.	Country/Region	Core papers	Percentage of core papers	Citations	Citations per paper
1	China	43	62.32%	3329	77.42
2	USA	8	11.59%	1098	137.25
3	Malaysia	6	8.70%	416	69.33
4	India	4	5.80%	263	65.75
5	Iran	3	4.35%	209	69.67
6	Saudi Arabia	3	4.35%	206	68.67
7	South Korea	2	2.90%	135	67.50
8	Italy	2	2.90%	127	63.50
9	Turkey	2	2.90%	116	58.00
10	Singapore	2	2.90%	128	64.00

Table 1.2.2 Institutions with the greatest output of core papers on the "application of nano-composite materials in wastewater treatment"

No.	Institution	Core papers	Percentage of core papers	Citations	Citations per paper
1	Hunan Univ	9	13.04%	1064	118.22
2	South China Univ Technol	5	7.25%	531	106.20
3	Chinese Acad Sci	5	7.25%	391	78.20
4	Yanshan Univ	5	7.25%	450	90.00
5	Cent S Univ	3	4.35%	470	156.67
6	Univ Kebangsaan Malaysia	3	4.35%	253	84.33
7	Univ Teknol Malaysia	3	4.35%	163	54.00
8	Fuzhou Univ	2	2.90%	228	114.00
9	Wuhan Univ Technol	2	2.90%	169	84.50
10	Nanyang Technol Univ	2	2.90%	128	64.00

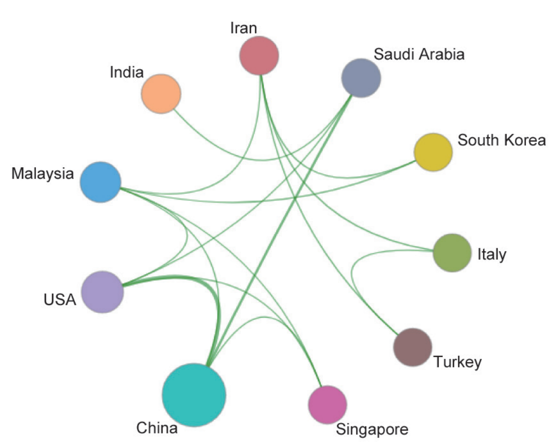

Figure 1.2.1 Collaboration network among major countries or regions in the engineering research front of "application of nano-composite materials in wastewater treatment"

1.2.2 Climate change and the ecological environment

Climate change is not only causing a rise of global mean surface temperatures and global warming, but also leading to increases in the number and severity of disasters. Thousands of people die from climate change related events each year, and the ecological environment is being greatly affected. The impacts of climate change on the ecological environment have attracted the attention of various countries around the world. In China, climate change is being considered in the layout of ecological and civil construction projects.

In order to understand the impacts of climate change on different aspects of the world, the Intergovernmental Panel on Climate Change (IPCC) has released five climate change assessment reports, which discuss the scientific facts, impacts,

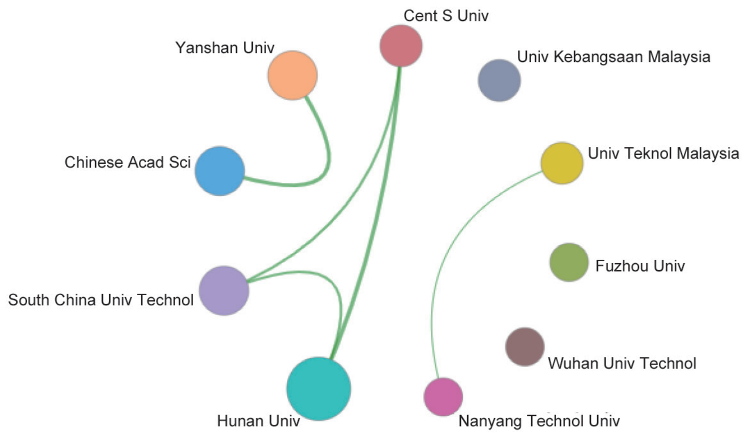

Figure 1.2.2 Collaboration network among major institutions in the engineering research front of "application of nano-composite materials in wastewater treatment"

Table 1.2.3 Countries or regions with the greatest output of citing papers on the "application of nano-composite materials in wastewater treatment"

No.	Country/Region	Citing papers	Percentage of citing papers	Mean year
1	China	2726	55.95%	2017.5
2	USA	441	9.05%	2017.3
3	India	423	8.68%	2017.5
4	Iran	370	7.59%	2017.4
5	South Korea	204	4.19%	2017.4
6	Malaysia	153	3.14%	2017.2
7	Australia	141	2.89%	2017.3
8	Saudi Arabia	140	2.87%	2017.1
9	Singapore	100	2.05%	2017.4
10	Canada	88	1.81%	2017.5

Table 1.2.4 Institutions with the greatest output of citing papers on the "application of nano-composite materials in wastewater treatment"

No.	Institution	Citing papers	Percentage of citing papers	Mean year
1	Hunan Univ	280	23.53%	2017.8
2	Chinese Acad Sci	273	22.94%	2017.5
3	Cent S Univ	96	8.07%	2017.7
4	Jiangsu Univ	81	6.81%	2017.5
5	Univ Chinese Acad Sci	75	6.30%	2017.8
6	Islamic Azad Univ	71	5.97%	2017.2
7	Harbin Inst Technol	70	5.88%	2017.5
8	South China Univ Technol	69	5.80%	2017.9
9	Univ Teknol Malaysia	59	4.96%	2017.3
10	Tianjin Univ	59	4.96%	2017.3

adaptation measures, and mitigation strategies. Impact assessment reports on climate change in different areas are published from time to time. In 2019, the *Global Assessment of Biodiversity and Ecosystem Services*, the *Special Report on Climate Change and Land*, and the *Special Report on Oceans and the Cryosphere in Climate Change* were published. The *Special Report on Climate Change and Land* shows that better land management can help society adapt to climate change. With the expected increases in population and the negative impacts of climate change on vegetation, land must retain its productivity to maintain food security. The *Special Report on Oceans and the Cryosphere in Climate Change* aims to assess how climate change will affect the oceans and marine life, as well as areas where water exists in solid form, such as polar or alpine regions, and to assess the impacts of climate change on communities around the world and the options for adapting to climate change for a more sustainable future. The knowledge assessed in the report provides an overview of the climate-related risks and challenges that people around the world are currently experiencing and that future generations will face. It proposes adaptation options to deal with unavoidable changes, programs to manage and control related risks, and programs to build resilience for a sustainable future.

At present, in addition to the impacts of climate change on land and the oceanic cryosphere, studies also are being carried out on the establishment of new climate carrying capacities, urbanization climate effects, regional air pollution control strategies, and the protection of watersheds and other vulnerable areas, with considerations given to both the characteristics of economic and social development and the integrity of ecosystem services.

Table 1.2.5 shows the main output countries or regions for core papers in this engineering research front. It can be found that the USA ranks first in both the proportion of papers and the frequency of citations. Other countries have a big gap with the USA, which indicates that the USA has great research advantages in this respect. China has a relatively small number of core papers in this area, ranking sixth. In terms of the major output countries or regional cooperation networks (Figure 1.2.3), each country has shown extensive cooperation with the USA, and many countries also have cooperated extensively. Table 1.2.6 shows the main output organizations for core papers in this engineering research front. The institution that has published the most core papers is in China. According to the main inter-agency cooperation network (Figure 1.2.4), the Chinese Academy of Sciences has worked in cooperation with the other nine major institutions including the National Oceanic and Atmospheric Administration US Department of Commerce, Columbia University, and the National Center for Atmospheric Research, and the cooperation among these 10 institutions also has been very close. In the rankings of countries or regions that cite core papers, China ranks fifth, and there is still a big gap between the top ranked countries (Table 1.2.7); the Chinese Academy of Sciences ranks first among the institutions that cite core papers (Table 1.2.8). It can be seen that the USA is not only ahead of the world in the study of “climate change and the ecological environment,” but also has worked in close cooperation with other countries; however, the Chinese Academy of Sciences is also in a leading position among the research institutions in this field and should continue to maintain a relevant research focus on this front.

Table 1.2.5 Countries or regions with the greatest output of core papers on “climate change and the ecological environment”

No.	Country/Region	Core papers	Percentage of core papers	Citations	Percentage of citations	Citations per paper
1	USA	847	60.50%	190 153	62.61%	224.50
2	UK	455	32.50%	108 554	35.74%	238.58
3	Australia	311	22.21%	76 281	25.12%	245.28
4	Germany	299	21.36%	75 125	24.74%	251.25
5	France	252	18.00%	60 795	20.02%	241.25
6	China	224	16.00%	50 343	16.58%	224.75
7	Canada	217	15.50%	54 853	18.06%	252.78
8	Netherlands	207	14.79%	53 571	17.64%	258.80
9	Switzerland	177	12.64%	46 432	15.29%	262.33
10	Sweden	143	10.21%	36 842	12.13%	257.64

Table 1.2.6 Institutions with the greatest output of core papers on “climate change and the ecological environment”

No.	Institution	Core papers	Percentage of core papers	Citations	Percentage of citations	Citations per paper
1	Chinese Acad Sci	100	7.14%	22 942	7.55%	229.42
2	NOAA	93	6.64%	19 773	6.51%	212.61
3	Columbia Univ	80	5.71%	20 041	6.60%	250.51
4	Natl Ctr Atmospher Res	71	5.07%	16 546	5.45%	233.04
5	NASA	71	5.07%	15 969	5.26%	224.92
6	Univ Maryland	69	4.93%	18 395	6.06%	266.59
7	Univ Washington	64	4.57%	16 506	5.43%	257.91
8	Univ Exeter	63	4.50%	14 846	4.89%	235.65
9	Univ Calif Berkeley	62	4.43%	14 244	4.69%	229.74
10	Univ Colorado	61	4.36%	15 725	5.18%	257.79

NOAA: National Oceanic and Atmospheric Administration US Department of Commerce; NASA: National Aeronautics and Space Administration.

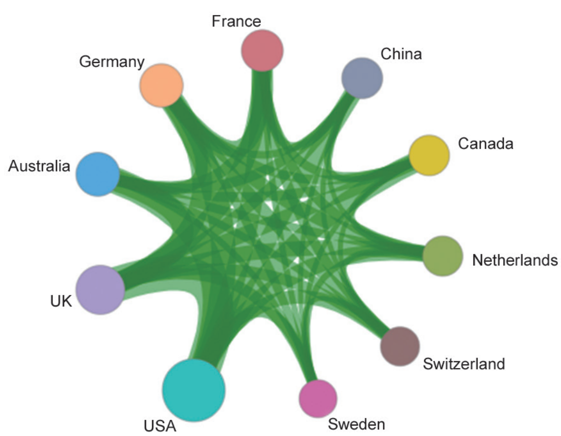

Figure 1.2.3 Collaboration network among major countries or regions in the engineering research front of “climate change and the ecological environment”

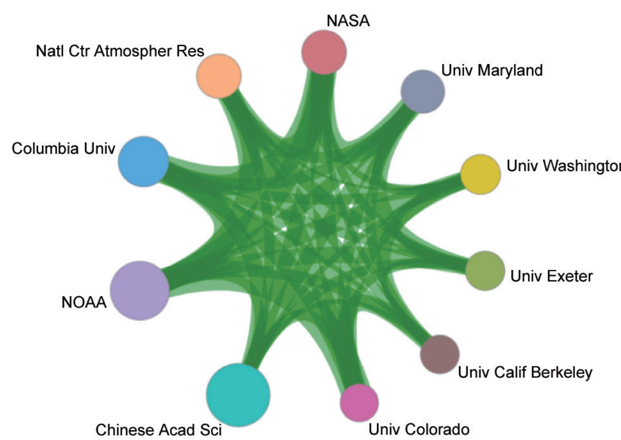

Figure 1.2.4 Collaboration network among major institutions in the engineering research front of “climate change and the ecological environment”

Table 1.2.7 Countries or regions with the greatest output of citing papers on “climate change and the ecological environment”

No.	Country/Region	Citing papers	Percentage of citing papers	Mean year
1	USA	997	25.02%	2014.8
2	UK	530	13.30%	2014.9
3	Germany	377	9.46%	2014.9
4	Australia	365	9.16%	2015.0
5	China	343	8.61%	2015.3
6	France	287	7.20%	2014.9
7	Canada	261	6.55%	2015.0
8	Netherlands	256	6.42%	2015.1
9	Switzerland	220	5.52%	2015.0
10	Spain	181	4.54%	2015.1

Table 1.2.8 Institutions with the greatest output of citing papers on "climate change and the ecological environment"

No.	Institution	Citing papers	Percentage of citing papers	Mean year
1	Chinese Acad Sci	110	11.98%	2015.1
2	Univ Calif Berkeley	91	9.91%	2014.8
3	Stanford Univ	87	9.48%	2015.1
4	Univ Washington	87	9.48%	2015.4
5	Univ Oxford	86	9.37%	2015.5
6	Univ Colorado	82	8.93%	2015.1
7	Columbia Univ	81	8.82%	2015.1
8	NOAA	81	8.82%	2014.5
9	Univ Maryland	72	7.84%	2015.2
10	Harvard Univ	71	7.73%	2015.5

1.2.3 Preparation and application of highly efficient oil–water separation materials

The continuous discharge of oily industrial wastewater and domestic sewage and the frequent occurrence of marine oil spill accidents have resulted in the formation of a large number of oil–water mixtures, which are causing environmental pollution and economic losses. Thus, the development of oil–water separation technology has important practical significance and application value. The presence of oil contaminants in the water will hinder the exchange of water and air and the normal incidence of sunlight, thus causing fatal damage to aquatic organisms, and the oil contains a large number of mutagenic and carcinogenic hydrocarbon compounds that will pass through water bodies. Such contaminants ingested in the food chain and eventually enriched in the human body pose a serious threat to human health. Therefore, water pollution is a global problem that needs to be solved urgently. When the oil enters a water body, it will form four types of oil–water mixtures, namely, oil slicks, dispersed oil, emulsified oil, and dissolved oil. The oil slicks and dispersed oil easily coalesce into a continuous oil layer due to the large particle size. Adsorption, sedimentation, and mechanical simmering oils can be easily removed; for the separation of relatively stable emulsified oils and dissolved oils, traditional demulsification techniques such as sedimentation, biological methods, ultra/microfiltration membrane separation, etc., can be used. While a certain separation effect can be obtained with these methods, there still are limitations related to the high energy consumption and low processing efficiency of such techniques. At present, oil–water separation technology is the focus of research in all countries around the world. The main research directions in this field focus on the preparation of fiber-based, high-efficiency oil–water separation membranes, the synthesis of new high-efficiency oil–water separation materials, the construction of super-infiltration oil–water separation systems, and the development of ceramic-based/bio-based oil–water separation materials, among other aspects.

Through the interpretations of core papers on the preparation and application of highly efficient oil–water separation materials, it was found that the core papers in this front of research were cited 94.00 times (Table 1.1.1). Among them, the main research areas were located in China, Singapore, and the USA. Among these countries, the number of core papers published by China accounted for 64.71% of the total, and citations per paper was 92.45 times, which represents the leading position (Table 1.2.9); Singapore, the USA, and Saudi Arabia showed relatively close cooperation in this field, and China displayed strong independent research and development capabilities in this field (Figure 1.2.5). Among major institutions, National University of Singapore, Donghua University, and Northeast Forestry University occupied the top three, and their core papers were frequently cited (Table 1.2.10). These major institutions showed a preference for independent research and development in this field, and only the National University of Singapore, King Abdullah University of Science and Technology, and Kraton Polymers LLC have conducted collaborative activities (Figure 1.2.6).

According to the rankings of the top ten countries or regions and institutions that cited the core papers, China, the USA, Singapore, and Canada have paid more attention to this research front; moreover, there are nine Chinese institutions among the top ten institutions (Tables 1.2.11 and 1.2.12).

In summary, China is in the leading position in the research and preparation of high-efficiency oil–water separation materials, but there has been little regional cooperation. It is recommended that China continue to increase investments in this front and promote the accelerated development of relevant research levels around the world.

Table 1.2.9 Countries or regions with the greatest output of core papers on "preparation and application of highly efficient oil–water separation materials"

No.	Country/Region	Core papers	Percentage of core papers	Citations	Citations per paper
1	China	11	64.71%	1017	92.45
2	Singapore	4	23.53%	448	112.00
3	USA	3	17.65%	212	70.67
4	Saudi Arabia	1	5.88%	84	84.00
5	Japan	1	5.88%	58	58.00

Table 1.2.10 Institutions with the greatest output of core papers on "preparation and application of highly efficient oil–water separation materials"

No.	Institution	Core papers	Percentage of core papers	Citations	Citations per paper
1	Natl Univ Singapore	3	17.65%	206	68.67
2	Donghua Univ	2	11.76%	363	181.50
3	Northeast Forestry Univ	2	11.76%	172	86.00
4	Nanyang Technol Univ	1	5.88%	242	242.00
5	Shanghai Jiao Tong Univ	1	5.88%	100	100.00
6	King Abdullah Univ Sci & Technol	1	5.88%	84	84.00
7	Kraton Polymers LLC	1	5.88%	84	84.00
8	Univ Akron	1	5.88%	75	75.00
9	China Univ Petr	1	5.88%	72	72.00
10	Natl Engn & Technol Res Ctr Wood Based Resources	1	5.88%	70	70.00

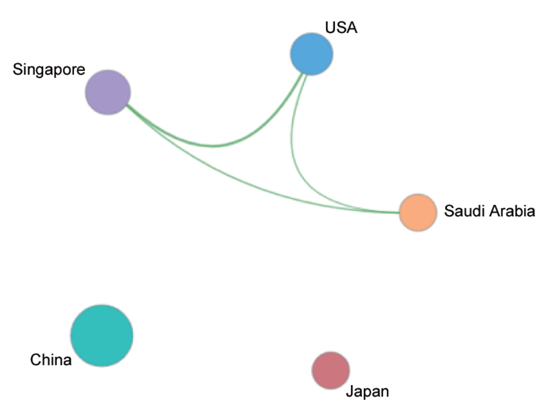

Figure 1.2.5 Collaboration network among major countries or regions in the engineering research front of "preparation and application of highly efficient oil–water separation materials"

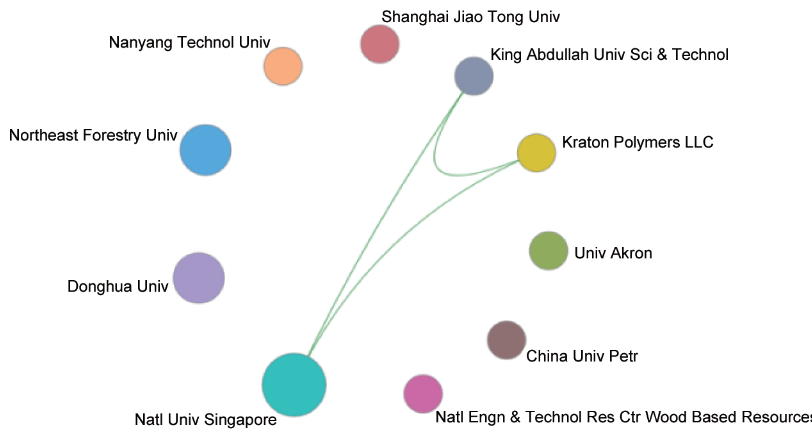

Figure 1.2.6 Collaboration network among major institutions in the engineering research front of "preparation and application of highly efficient oil–water separation materials"

Table 1.2.11 Countries or regions with the greatest output of citing papers on "preparation and application of highly efficient oil–water separation materials"

No.	Country/Region	Citing papers	Percentage of citing papers	Mean year
1	China	918	66.96%	2017.5
2	USA	115	8.39%	2017.5
3	Singapore	57	4.16%	2016.9
4	Canada	48	3.50%	2017.8
5	India	46	3.36%	2017.6
6	Japan	38	2.77%	2017.2
7	South Korea	36	2.63%	2017.1
8	Saudi Arabia	31	2.26%	2016.8
9	Australia	30	2.19%	2016.9
10	UK	26	1.90%	2017.5

Table 1.2.12 Institutions with the greatest output of citing papers on "preparation and application of highly efficient oil–water separation materials"

No.	Institution	Citing papers	Percentage of citing papers	Mean year
1	Chinese Acad Sci	116	24.89%	2017.3
2	Donghua Univ	66	14.16%	2016.9
3	Univ Chinese Acad Sci	46	9.87%	2017.3
4	South China Univ Technol	40	8.58%	2017.7
5	Hubei Univ	31	6.65%	2017.3
6	Harbin Inst Technol	30	6.44%	2017.5
7	Natl Univ Singapore	30	6.44%	2016.3
8	Jiangsu Univ	30	6.44%	2017.9
9	Soochow Univ	27	5.79%	2017.5
10	Zhejiang Univ	26	5.58%	2017.0

2 Engineering development fronts

2.1 Trends in top 10 engineering development fronts

The top 10 engineering development fronts in the field of environmental engineering are summarized in Table 2.1.1., and these include the subfields of environmental science engineering, meteorological science engineering, marine science engineering, food science engineering, textile science engineering, and light industry science engineering. The number of patents between 2013 and 2018 related to these individual topics are summarized in Table 2.1.2.

(1) Multi-technology coordinated soil pollution remediation

In recent years, soil pollution and its environmental risks have emerged as a prominent issue in China, and the level of soil pollution is serious in some areas. Because of the coexistence of various types of old and new pollutants, inorganic and organic pollution, and multi-media (soil–water) pollution, there is an urgent need to develop multi-technology coordinated soil pollution remediation technology.

Traditional soil remediation techniques including physical, chemical, and biological remediation, have limitations in terms of pollutants, remediation time, and cost. Compared with a single processing technology, multi-technology coordinated soil pollution remediation systems (such

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

No.	Engineering development front	Published patents	Citations	Citations per paper	Mean year
1	Multi-technology coordinated soil pollution remediation	1119	1170	1.05	2016.6
2	Complex microbial communities useful for processing sewage	117	92	0.79	2016.7
3	Environmental nanocatalysts	1000	5022	5.02	2015.5
4	Development of membrane separation materials and processes	47	158	3.36	2014.4
5	Intelligent weather forecasting technology	744	5376	7.23	2015.8
6	Efficient and comprehensive utilization of ocean energy technology	1258	8690	6.91	2015.5
7	Integrated ocean environment observing technology	1301	3103	2.39	2016.1
8	Rapid and accurate detection of food-borne pathogenic microorganisms	1000	17 494	17.49	2012.9
9	3D printing system with fiber	3147	12 351	3.92	2016.4
10	Biomass energy conversion technology	1000	19 943	19.94	2012.8

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	2013	2014	2015	2016	2017	2018
1	Multi-technology coordinated soil pollution remediation	32	72	111	200	235	444
2	Complex microbial communities useful for processing sewage	2	4	16	23	32	40
3	Environmental nanocatalysts	51	61	60	118	252	305
4	Development of membrane separation materials and processes	2	11	2	10	5	7
5	Intelligent weather forecasting technology	53	51	84	152	139	206
6	Efficient and comprehensive utilization of ocean energy technology	190	213	198	270	217	170
7	Integrated ocean environment observing technology	132	138	158	240	293	340
8	Rapid and accurate detection of food-borne pathogenic microorganisms	82	93	98	122	99	140
9	3D printing system with fiber	99	155	379	559	863	1008
10	Biomass energy conversion technology	134	144	100	95	65	27

as chemical oxidation–microbial degradation of organic pollutants, combination technology involving soil vapor extraction and thermal desorption, combination technology involving elution and bioremediation) are more adaptable during the treatment of different types of combined pollutants, as well as multi-media pollution. Multi-technology coordinated soil pollution remediation technology has developed rapidly in recent years. In particular, the number of patents has increased from 32 in 2013 to 444 in 2018, and the number has increased year by year. Remediation technology has gradually changed from single pollutant treatment to multiple pollutant treatment, from ex-situ, fixed equipment to in-situ, automatic and intelligent equipment, and from pollutant removal to combined control of processing regulation and terminal treatments.

China presently lacks original, integrated technology, and equipment. Demonstrations of integrated remediation technology for special high-risk contaminated sites such as electronic waste sites and highly contaminated petroleum soil are limited. Searching for modular, automatic, and intelligent integrated remediation technology and equipment should be a priority focus area in the future.

(2) Complex microbial communities useful for processing sewage

Complex microbial communities are generally composed of many different types of microorganisms capable of degrading pollutants to various degrees. These communities contain mutually beneficial and coexisting mixed organisms. The pollutants are gradually degraded during processes in which the growth and metabolism of microorganisms occur, thus achieving the purpose of purifying sewage. The main ways to obtain strains for complex microbial communities are as follows: 1) to purchase microorganisms from preservation institutions; 2) to screen for wild-type microorganisms from the natural environment; 3) to modify or stimulate the degradation performance of microorganisms by means of genetic engineering; and 4) to induce specific metabolic pathways of microorganisms through domestication and the retention of strains that degrade specific compounds. Compared with conventional sewage treatment technology, the complex microbial communities can be directly added to sewage without any additional equipment or process. The use of complex microbial communities in treatment technology has obvious advantages such as convenient operations, economic efficiency, wide application ranges, and no secondary pollution. Presently, such communities have been used in industrial, agricultural, pharmaceutical, and animal husbandry sewage treatment processes. Although there have been numerous related research projects and patents on complex microbial communities for sewage treatments, there are still some problems facing this field, such as the dispersion of products from the complex microbial communities and the influences of environmental factors on the treatment effects of complex microbial communities, especially in domestic research. Therefore, it will be necessary to further study this technology to achieve specific, efficient, and inexpensive complex microbial communities that are optimal for local applications. Additionally, by standardizing the use of products of complex microbial communities, countries can avoid the economic losses and ecological imbalances caused by misuse.

(3) Environmental nanocatalysts

Nanomaterials refer to materials with a size of 1–100 nm in at least one dimension. Many nanomaterials (including metal oxides, noble metals, carbonaceous materials) have exhibited huge advantages in the catalytic degradation or transformation of pollutants due to their large specific surface area and high reactivity, and thus, these materials have become the focus of environmental catalyst development. This development front mainly is focused on the following technologies: 1) nano-photocatalysts, especially those responsive to visible light, for the degradation of gaseous pollutants such as formaldehyde and aqueous pollutants such as dyes; 2) three-way nanocatalysts, for redox transformation of CO, carbohydrates, and NO_x from the automobile exhaust gas to CO_2, N_2, and H_2O; 3) nanocatalysts for atmospheric pollution control such as flue gas treatment, etc.; 4) nanocatalysts for water treatment, such as for catalytic ozonation and catalytic Fenton oxidation reactions, etc.; and 5) electronanocatalysts for hydrogen production, etc. The developed materials mainly include rare earth nanomaterials, bismuth-based nanomaterials, transition metal oxide nanomaterials, g-C_3N_4 nanocomposites, graphene nanocomposites, quantum dot nanocatalysts, and magnetic nanocatalysts.

In order to overcome the difficulty of manipulating nanomaterials in engineering applications, it is a generally accepted strategy to fabricate nanocomposites via the immobilization of nanoparticles in porous hosts of a large size. According to the different application scenarios, the hosts should also be resistant to high temperatures, oxidation, etc. Honeycomb ceramics, porous ceramic balls, and ceramsites have been extensively developed as hosts for nanocatalysts. However, it is important to develop new immobilization technologies to extend the function of the hosts from simple supports to more advanced features such as pollutant enrichment and activity modulation of embedded nanoparticles.

(4) Development of membrane separation materials and processes

Membrane separation technology is widely used in water treatment applications, mainly for industrial sewage recycling, municipal sewage treatment, municipal drinking water treatment, and seawater desalination. The key to the efficiency of membrane separation technology lies in the membrane materials and processes employed. In the future, the hot topics and frontiers of membrane separation technology will likely be focused on the R&D of high-performance membrane materials and modules, as well as the development and optimization of membrane separation processes and reactors.

In regard to the R&D of membrane materials, China has currently established a certain technological foundation and industrial scale for R&D activities and production of polymer membrane materials involved in ultrafiltration, microfiltration, nanofiltration, ion exchange, and other technologies, but research in China remains relatively weak in terms of gas membranes, liquid membranes, highly selective nanofiltration, reverse osmosis membranes, and other fields. In terms of reverse osmosis membranes used in seawater desalination and strong brine reduction/zero emission technology, there remains gaps between domestic and foreign products in regard to several aspects including special ion removal, temperature sensitivity, energy consumption per ton of water produced, and long-term operation stability. Novel nano-material compositions, two-phase interface fine controls, and low flow resistance are the key technologies to solving the above problems and shortening the gaps. In addition, for membrane separation technology, the diversity of water quality characteristics requires membrane materials to have a broad-spectrum fouling resistance, and thus, research on mixed matrix membrane materials and novel structure-designed membrane materials is getting more attention; such research has become a hot topic in the R&D of membrane materials in recent years.

In regard to the R&D of membrane modules, the development of low/ultra-low pressure anti-fouling membrane modules is the main direction for improving the membrane separation capacity and service life, as well as for solving the problem of membrane blocking and fouling. In particular, the development and optimization of the membrane module preparation process has become a hot topic. Through the optimization of the coating method, as well as through R&D for online detection technologies, automatic film rolling machines, and other hardware facilities, the separation performance, homogeneity, and stability of membrane modules can be improved. In addition, China needs to reduce its dependence on imports of pumps, valves, energy recovery devices, and pressure vessels, which are key parts related to the membrane separation system and its components, and instead, China should develop self-owned technologies and products.

In regard to the optimization of the membrane separation process, in recent years, with the continual improvements in the requirements and standards for industrial water reuse and strong brine emission reductions, membrane system integration coupling, emission reduction, and zero emission technology have raised the low consumption and high efficiency requirements for membrane processes. For example, the continuous microfiltration/continuous ultrafiltration (CMF/CUF) + reverse osmosis coupling process has been demonstrated to have application advantages and potential for seawater desalination and sewage reuse. The CMF/CUF process can improve the subsequent reverse osmosis inlet water quality without the addition of any flocculant, fungicide, or residual chlorine remover, and it has the advantages of extending the service life of reverse osmosis membranes, improving the recovery rate of the system, reducing the equipment occupation area and operating costs, reducing the labor intensity, realizing automatic control, and so on. Anaerobic membrane bioreactors have shown good application prospects in the low-consumption and high-efficiency treatment of highly concentrated organic wastewater and municipal sewage. Future research will focus on how to better control membrane fouling and large-scale engineering applications.

(5) Intelligent weather forecasting technology

Weather forecasting is a science of prediction, and thus, it is impossible to achieve 100% accuracy. The essence of forecasting involves the use of supercomputer calculations based on massive datasets, which are produced according to known meteorological conditions. However, there will be inevitable deviations between the calculated results and the real weather conditions. To make the weather forecasts more accurate, a process to continuously narrow the gap between the calculation results and the real situation is needed, and this has proved to be a difficult problem in the real world. The weather forecasts mainly depend on big data at different temporal and spatial scales, which is a very good situation for the use of artificial intelligence. On the one hand, sufficient meteorological data provides support for the advancement of artificial intelligence technology; on the other hand, the application of artificial intelligence technology will effectively promote the accuracy of the calculation results and calculation speed of weather forecasts, thus making "the weather forecast more accurate." Recently, a research team in Japan has developed a new high-precision identification method using deep learning technology, which can identify the characteristics of tropical depressions in the Northwest Pacific Ocean one week before the occurrence of a typhoon. As these data can be used to predict the occurrence of a typhoon one week in advance, the data can cause great concern and need to be accurate. The artificial intelligence algorithm corrects the results of a supercomputer as much as possible, automatically and without human intervention, to be closer to the actual observation data, thus achieving the ultimate goal of "more and more accurate weather forecasts."

In the field of artificial intelligence, computing power, algorithms, and data are indispensable. The use of high-performance computers in meteorological departments can provide a foundation for the development of intelligent weather forecasts.

(6) Efficient and comprehensive utilization of ocean energy technology

Ocean energy refers to the renewable energy derived from infrastructure installed in seawater. The ocean receives, stores, and emits energy through various physical processes, which exist in the ocean in the form of tidal energy, wave energy, ocean thermal energy, ocean salinity energy, and ocean current energy. The utilization of ocean energy relies on the use of certain methods and equipment to convert various kinds of ocean energy into electrical energy or other available forms of energy. Ocean energy is a kind of new energy with strategic significance that needs to be developed urgently because of its advantages of reproducibility and non-polluting characteristics.

At present, the hot topics and main research directions in the field of efficient and comprehensive utilization of ocean energy technology include international tidal and tidewave energy technology, wave energy technology, ocean thermal energy technology, ocean salinity energy, and ocean current energy.

Marine energy reserves are typically large in size. According to preliminary estimates, the total theoretical installed capacity of China's ocean energy exceeds 2 billion kilowatts, three times the total installed capacity of China's electricity in 2007. Recently, the ocean energy industry has begun to take shape. The installation costs of ocean energy power generation equipment have been decreasing rapidly, which has accelerated the industrialization of ocean energy technology.

(7) Integrated ocean environment observing technology

Integrated ocean environment observing technology refers to the equipment and technology that is used to study the dynamic changes of the marine environment, and it includes satellites and aircraft, surface survey and observation vessels, surface anchor buoys, submerged buoys, drifting buoys, underwater mobile observation platforms, submarine observation platforms, shore-based observation platforms, etc.; this technology is used to obtain various marine environmental information in real time or in near real time, so as to realize stereoscopic observations of the marine environment. The development of integrated ocean environment observing technology is one of the keys to the future development of marine science and technology.

At present, the hot topics and main research directions in the field of integrated ocean environment observing technology include 1) multi-parameter, wide range, real-time, and three-dimensional satellite remote sensing of marine environment observations; 2) miniaturization, intelligence, standardization, and industrialization of sensors and detection equipment;

and 3) globalization, stratification, synthesis, and intelligent applications of ocean network observations.

Nowadays, there is already a relatively mature global planning framework that reaches around the world, and China has launched a plan to build a national integrated ocean observing network. In the long term, given the needs for marine activities centered on marine information services, an adaptive ocean environment stereoscopic observation network composed of multiple platforms remains an important development direction of integrated ocean environment observing technology.

(8) Rapid and accurate detection of food-borne pathogenic microorganisms

With the change of food consumption patterns in China, the risk of food-borne pathogenic microorganisms has gradually increased, and dealing with these risks will be necessary for ensuring food safety in China in the future. Rapid detection of food-borne pathogens has long been a difficult problem in the field of microbiology. The traditional technology for food microorganism detection mainly relies on methods such as culture enrichment, separation and purification, biochemical analyses, and so on. However, the current process suffers from problems such as low efficiency, long detection times, and unsatisfying sensitivity, and it is unable to meet the safety detection requirements of the modern food industry. Therefore, it is imperative to develop novel food-borne pathogen rapid detection technology with a high sensitivity, high throughput, high accuracy, and rapid detection capacity. There are two major directions for the future development of rapid detection techniques, and these include time shortening for single pathogen detection and simultaneous detection of multiple samples. Among the various new rapid detection technologies for food-borne pathogenic microorganisms, constant temperature amplification detection technology and immunoassay technology may become the main development directions in the future. Combinations of different detection technologies are another research focus in the development of rapid detection technology for food-borne pathogenic microorganisms.

(9) 3D printing system with fiber

Three-dimensional printing technology is based on digital model files. By adding printing ink, a printer can customize the required shape through the integration of line to plane and plane to 3D structure rapid prototyping technology. The 3D printing of fiber-based materials uses fiber-based material as raw material to prepare printing ink and customize the sample structure needed as defined through 3D printing technology. The 3D printing technology prints interwoven fibrous structures, generally at the micron level, and with it, one can achieve structural control from micro to macro scales; this technology is suitable for making some special woven structures. At present, the main application fields of fiber-based material 3D printing are smart wearable textiles, flexible electronic components, high-performance composite materials, and so on. The collection and monitoring of human biological signals, the integration of customized electronic devices, and the enhancement of materials through orientation are the main application directions. A likely trend in the future will involve the use of compound inks to print, realize multi-component printing, and support unique sample performances. Due to its extensive and advanced application field, the further development of fiber-based material 3D printing technology can be expected.

(10) Biomass energy conversion technology

The extensive use of non-renewable fossil energy such as coal, oil, and natural gas has caused serious environmental problems. Therefore, developing green energy is critical for human society to fulfill the demands for energy in the future and simultaneously to solve environmental problems. Biomass energy will play an important role in the development of green energy, as it is one of the promising alternatives to replace fossil energy in the future.

Biomass energy conversion mainly refers to the conversion of biomass energy into secondary energy by biochemical methods, physical methods, thermochemical methods, and other technologies. The converted secondary energy includes heat or electricity, solid fuel (charcoal or molding fuel), liquid fuels (biodiesel, methanol, ethanol, vegetable oil, etc.), and gaseous fuels (hydrogen, biomass gas, and biogas). There are a variety of biomass sources, and accordingly, the technologies for biomass energy conversion are numerous. Currently, biomass energy conversion still faces many challenges in terms of practical utilization and cost effectiveness. As a consequence, it will be critically important to develop low-cost and efficient techniques for realizing the industrialization of biomass energy conversion in the future.

2.2 Interpretations for three key engineering development fronts

2.2.1 Multi-technology coordinated soil pollution remediation

Soil pollution is usually regional, complex, and of a multi-media nature. Traditional physical, chemical, and biological remediation technologies typically have limitations such as pollutant type restrictions, long remediation times, or high costs, which makes it difficult to remediate soil pollution efficiently and economically. Multi-technology coordinated soil pollution remediation technologies include integrated equipment of thermal desorption, vapor extraction, elution, and oxidation, and new materials (microbial agents, biochar, nanomaterials, biomass-mineral composite materials, etc.) for the stabilization or degradation of soil pollution, as well as improved devices for energy optimization (electric, microwaves, solar energy, plasma) and chemical/microbial/plant remediation.

In recent years, soil remediation technology has developed rapidly in China, and the R&D investments have remained in the top rank worldwide. As shown in Table 2.2.1, China has issued 998 patents on multi-technology coordinated soil pollution remediation over a recent five year period, which represents 73.16% of all of the 1119 patents issued. Japan and South Korea ranked second and third, with 40 and 33 patents, respectively. The total number of patents for multi-technology coordinated soil pollution remediation in China was much higher than that in developed countries such as Japan and the USA.

In terms of the citation frequency (Table 2.2.1), the citations per paper in China was only 0.86, a value much lower than that in developed countries such as the USA and Japan, which lack of original techniques, innovation, and influence. As for the relevance (Figure 2.2.1), a strong correlation existed between the USA and Japan, while China had no cooperative relationship with other developed countries. Developed countries such as the USA and Japan have focused on source disposal and end-treatment technology such as renewable remediation materials; however, materials used in chemical–biological remediation processes and the invention of integrated remediation equipment were the primary focus areas in China. As the integrated remediation technology and equipment is relatively mature in developed countries, it is imperative to develop integrated remediation technology and equipment systems based on advanced sources and process control-end treatments.

The top 10 patents output institutions were all from China (Table 2.2.2). The multi-technology coordinated soil pollution remediation technology market has gradually become mature. Jiangsu Gaiya Environmental Technology Co., Ltd., had the largest number of disclosed patents, and these were mainly related to in-situ and ex-situ soil remediation equipment and agents. Chengdu Shengling Biotechnology Co., Ltd., and Jiangsu Shibang Bioengineering Technology Co., Ltd., ranked as the second and fifth, respectively, with a focus on the microbial agents and materials for soil remediation. Qingdao University of Technology and Hunan Agricultural University, which focused on the remediation of high-risk oil contaminated sites, heavy metal–organic compound contaminated soils, and combined remediation technology for biochar and plants, ranked as the third and fourth with 10 and 7 patents issued, respectively.

As shown in Figure 2.2.2, there was no cooperation between the universities and companies. Thus, industry–university–research collaboration is still challenging. Patents mainly focused on the development of microbial agents and new materials, and presently, research and development on integrated technology and equipment need to be strengthened. Furthermore, high-tech companies have begun to step into the industry of soil remediation, while mainly focusing on chip development and process operations for soil remediation equipment. Trends indicate that soil remediation is gradually becoming more modularized, automatic, and intelligent in China.

2.2.2 Efficient and comprehensive utilization of ocean energy technology

Ocean energy refers to renewable energy derived from infrastructure installed in seawater, and it includes tidal energy, wave energy, ocean thermal energy, ocean salinity energy, ocean current energy, etc. In a broad sense, ocean energy also includes wind energy over the ocean, solar energy on the ocean surface, and ocean biomass energy. According to the storage forms, it can be divided into mechanical energy, heat energy, and chemical energy. Ocean energy has the characteristics of large reserves, sustainable use, and green and clean processes, and it is one of the most important

Table 2.2.1 Countries or regions with the greatest output of core patents on "multi-technology coordinated soil pollution remediation"

No.	Country/Region	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	China	998	89.19%	856	73.16%	0.86
2	Japan	40	3.57%	186	15.90%	4.65
3	South Korea	33	2.95%	22	1.88%	0.67
4	USA	16	1.43%	41	3.50%	2.56
5	Taiwan of China	9	0.80%	0	0.00%	0.00
6	Canada	6	0.54%	5	0.43%	0.83
7	Russia	6	0.54%	0	0.00%	0.00
8	Belgium	2	0.18%	48	4.10%	24.00
9	Australia	2	0.18%	24	2.05%	12.00

Table 2.2.2 Institutions with the greatest output of core patents on "multi-technology coordinated soil pollution remediation"

No.	Institution	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	JSGY	21	1.88%	21	1.79%	1.00
2	CDSL	11	0.98%	8	0.68%	0.73
3	UNQT	10	0.89%	4	0.34%	0.40
4	UYAG	7	0.63%	14	1.20%	2.00
5	JSSB	7	0.63%	0	0.00%	0.00
6	SHGI	6	0.54%	6	0.51%	1.00
7	HSFH	6	0.54%	2	0.17%	0.33
8	ZZSQ	6	0.54%	0	0.00%	0.00
9	CAGS	5	0.45%	14	1.20%	2.80
10	UYHD	5	0.45%	14	1.20%	2.80

JSGY: Jiangsu Gaiya Environmental Technology Co., Ltd.; CDSL: Chengdu Shengling Biotechnology Co., Ltd.; UNQT: Qingdao University of Technology; UYAG: Hunan Agricultural University; JSSB: Jiangsu Shibang Bioengineering Technology Co., Ltd.; SHGI: Shanghai Geotechnical Investigation; HSFH: Hanshan Fenghua Supply & Marketing Co., Ltd.; ZZSQ: Zhengzhou Souqu Information Technology; CAGS: Shandong Academy of Agricultural Sciences Agri-food Institute; UYHD: North China Electric Power University.

choices for the global response to the shortages of fossil energy and climate warming, which will entail the widespread development of clean energy and the adjustment of the energy structure.

According to a research report published by the International Renewable Energy Agency (IRENA) in August 2014, international tidal energy technology is the most mature technology for deriving ocean energy, and it has a Technology Readiness Level (TRL) of 9 (commercial operation stage). The international tidewave energy TRL is 7–8 (full scale prototype under real sea conditions test stage). The wave energy TRL is 6–7 (engineering prototype under real sea conditions test stage). The ocean thermal energy TRL is 5–6 (real sea conditions test stage). The ocean salinity energy and ocean current energy TRL is 4–5 (laboratory technology validation stage).

The ocean energy industry has begun to take shape, with more than 2500 international organizations working in the industry. The installation costs of ocean energy power generation equipment have been decreasing rapidly, which has accelerated the industrialization of ocean energy technology. Current international ocean energy technology has not yet entered the stage of large-scale application, and to catch up with internationally advanced levels, we should

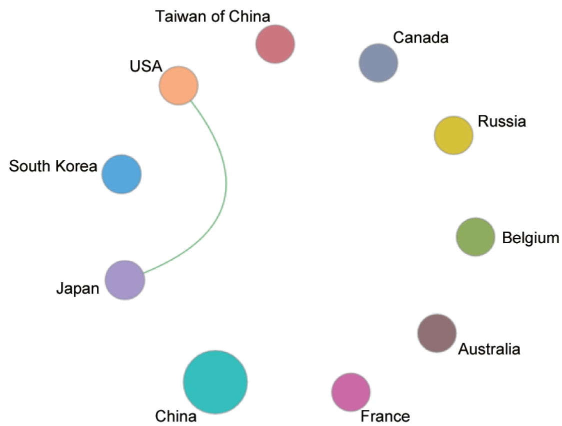

Figure 2.2.1 Collaboration network among major countries or regions in the engineering development front of "multi-technology coordinated soil pollution remediation"

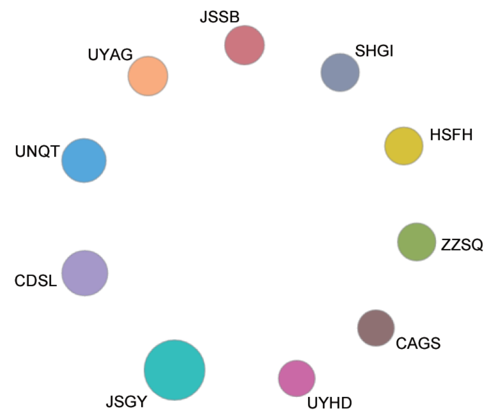

Figure 2.2.2 Collaboration network among major institutions in the engineering development front of "multi-technology coordinated soil pollution remediation"

focus on the "construction of marine power" and "construction of the marine silk road" recommendations in the 21st century. Such efforts constitute a strategic opportunity, through demonstration projects of stable operations that drive the development of technology, efforts to accelerate the cultivation of ocean energy industries, projects to initiate the large-scale development of islands, and the development of far-reaching marine resources to provide energy security.

It is estimated that there are over 75 billion kilowatts of ocean energy, among which wave energy represents 70 billion kilowatts, oceanic thermal energy represents 2 billion kilowatts, ocean current energy represents 1 billion kilowatts, and ocean salinity energy represents 1 billion kilowatts. According to preliminary estimates, the total theoretical installed capacity of China's offshore wind, tidal, wave, tidal, and salinity gradient energies, as well as temperature-difference energy in South China Sea exceeds 2 billion kilowatts, three times the total installed capacity of China's electricity in 2007.

Table 2.2.3 shows the countries or regions with the greatest output of core patents on the "efficient and comprehensive utilization of ocean energy technology." China ranked second in the number of core patent disclosures, and it showed only a little gap with Japan, which ranked first. However, the citations per patent for China were the lowest in the top 10 countries, accounting for only 1.21% of the total, which is far from the number for the USA. This shows that although China has many core patents in this field, these patents lack innovation and influence. Thus, China's technological level in this field still needs to be improved. As can be seen from the collaboration network (Figure 2.2.3) among the main countries or regions engaged in this front, the USA, Britain, and Germany each had cooperative relations with two countries, while China only has cooperated with the USA.

Table 2.2.4 shows the institutions with the greatest output of core patents. The top three institutions were General Electric Company (116), Siemens AG (48), and Rolls Royce Holdings PLC (29). China's Wuxi Jintianyang Laser Electronic Co., Ltd. ranks eighth, but the citations value was only 5, which was the lowest in the top 10. Figure 2.2.4 shows the collaboration network among the main institutions working on this front. There were weak associations in terms of research and development cooperation between individual institutes or enterprises in this field. Only General Electric Company and "Converteam Technology, Ltd." have had a cooperative relationship, and the patents of the two institutes were ranked top. This shows that we should further strengthen exchanges and cooperation with other countries and institutions in order to further enhance China's innovation ability in this field.

2.2.3 Rapid and accurate detection of food-borne pathogenic microorganisms

With the development of food supply systems, household consumption of semi-finished and instant foods has been growing rapidly, and so are safety risks from microorganism. Some of the most severe risks stem from semi-finished foods

Table 2.2.3 Countries or regions with the greatest output of core patents on “efficient and comprehensive utilization of ocean energy technology”

No.	Country/Region	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	Japan	233	18.52%	1330	15.30%	5.71
2	China	202	16.06%	105	1.21%	0.52
3	South Korea	199	15.82%	116	1.33%	0.58
4	USA	164	13.04%	2517	28.96%	15.35
5	UK	104	8.27%	1761	20.26%	16.93
6	Germany	88	7.00%	1089	12.53%	12.38
7	France	45	3.58%	266	3.06%	5.91
8	Norway	43	3.42%	419	4.82%	9.74
9	Ireland	20	1.59%	272	3.13%	13.60
10	Sweden	20	1.59%	87	1.00%	4.35

Table 2.2.4 Institutions with the greatest output of core patents on “efficient and comprehensive utilization of ocean energy technology”

No.	Institution	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	GENE	116	9.22%	2442	28.10%	21.05
2	SIEI	48	3.82%	766	8.81%	15.96
3	RORO	29	2.31%	161	1.85%	5.55
4	SMSU	28	2.23%	28	0.32%	1.00
5	DEWO	25	1.99%	6	0.07%	0.24
6	CONV	22	1.75%	806	9.28%	36.64
7	CATE	21	1.67%	57	0.66%	2.71
8	JLEC	20	1.59%	5	0.06%	0.25
9	OPEN	19	1.51%	283	3.26%	14.89
10	NIDE	19	1.51%	118	1.36%	6.21

GENE: General Electric Company; SIEI: Siemens AG; RORO: Rolls Royce Holdings PLC; SMSU: SAMSUNG Heavy Industries Ltd.; DEWO: Daewoo Shipbuilding & Marine Engineering Co., Ltd.; CONV: Converteam Technology Ltd.; CATE: Caterpillar Inc.; JLEC: Wuxi Jintianyang Laser Electronic Co., Ltd.; OPEN: Openhydro Group Ltd.; NIDE: NEC Corporation.

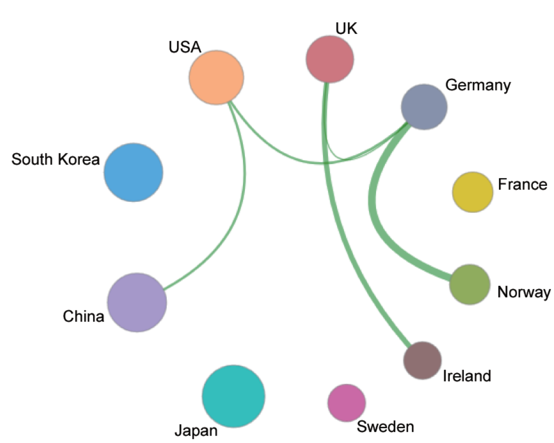

Figure 2.2.3 Collaboration network among major countries or regions in the engineering development front of “efficient and comprehensive utilization of ocean energy technology”

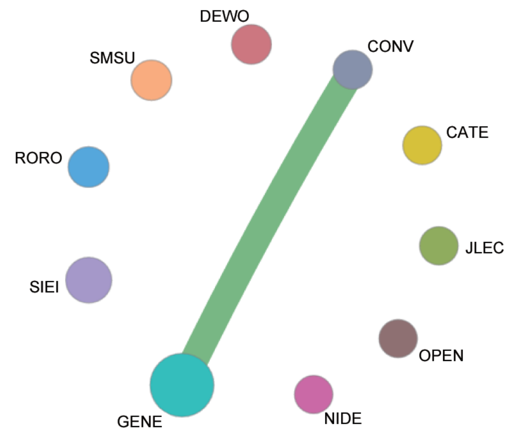

Figure 2.2.4 Collaboration network among major institutions in the engineering development front of “efficient and comprehensive utilization of ocean energy technology”

such as preliminary processed meat and vegetables, and instant foods such as cheese and salads, which often contain food-borne pathogenic microorganisms. Therefore, food-borne pathogenic microorganisms are the focus of food safety all over the world, and the proportion of food-borne pathogenic microorganism identification and detection technologies in the field of food safety analysis has been growing.

Rapid and accurate identification and detection of food-borne microorganisms is one of the most effective ways to prevent and control human food-borne diseases. At present, detection of food-borne pathogenic microorganisms is mainly based on the combination of enrichment culture and physiological and biochemical identification methods (Food Microbiology National Standard GB4789). These protocols are highly accurate. Therefore, such methods are indispensable for microbe detection and management domestically. However, culture based and biochemical identification methods have problems including long detection times, low throughput, and low efficiency. In addition, culture based and biochemical identification methods are only suitable for microorganisms that are highly active, and these methods cannot be used for microorganisms that are viable but non-culturable (VBNC) but can restore activity under proper conditions, proliferate rapidly in food, and thereby bring about safety risks. Traditional detection and identification methods for food-borne pathogens are thus more and more unable to meet the safety detection requirements of the modern food industry. Therefore, it is imperative to develop novel detection technologies for pathogenic bacteria that have a high sensitivity, high throughput, and rapid speed.

As a whole, the current rapid detection methodology can only be confined to the preliminary screening of food samples due to the limitations in accuracy and stability. There is still a lack of effective and rapid detection methods that can be used against pathogenic microorganisms at home and abroad. The USA has the most published patents on the rapid and accurate detection of food-borne pathogenic microorganisms. Developing stable, accurate, and sensitive rapid detection technology in advance would promise great advantages in improving food safety levels, promoting the development of the food industry, and stimulating import–export commerce.

There are two major directions for the future development of food-borne pathogen rapid detection technology, and these include time shortening for single pathogen detection and simultaneous detection of multiple samples. Combinations of different detection technologies represent another research focus, with the aim of balancing detection timeliness, sensitivity, and accuracy. Among various new rapid detection technologies for food-borne pathogenic microorganisms, constant temperature amplification detection technologies and immunoassay technologies may become the main development directions in the future.

As is shown in Table 2.2.5, China has published 127 core patents on rapid and accurate detection of food-borne pathogenic microorganisms, ranking second in the number of core patent disclosures, while the USA ranked first with 491 core patents. Japan and South Korea ranked third and fourth, with 95 and 66 patents respectively. The total number of core patents on rapid and accurate detection of food-borne pathogenic microorganisms in China was still not competitive with that in the USA, but was much higher than that in other countries. However, the citations per patent in China was the lowest (1.09) among the top 10 countries, which is much lower than that of the developed countries such as the USA (27.76), the Netherlands (16.54) and Germany(14.27), which expose a deficiency in original innovation and technological influence in patents from China.

The collaboration relationship among most developed countries engaged in this front are close and frequent, as can be seen from Figure 2.2.5. Among the top 10 countries, the USA has established firm cooperative partnership with all the other countries except South Korea. Switzerland has also built strong collaboration network with many countries from Europe and North America. China has only established cooperation relation with the USA, indicating an imperative urge to reinforce and seek more international communication and collaboration.

Table 2.2.6 shows the institutions with the greatest output of core patents on the rapid and accurate detection of food-borne pathogenic microorganisms. University Of California had the largest number of issued patents (25), followed by F. Hoffmann-La Roche AG (22), Massachusetts Institute of Technology (15), and National Council for Scientific Research (15). Figure 2.2.6 shows the collaboration network among the major institutions engaged in this front. There are already some research and development inter-institution collaboration among enterprises in this field. University Of California have had a cooperative relationship with both Massachusetts Institute of Technology and CALY Technologies, among which the patent number of University Of California and Massachusetts Institute of Technology ranked top three. This showed that inter-institution collaboration have a beneficial effect on technique innovation and entrepreneur development.

Table 2.2.5 Countries or regions with the greatest output of core patents on the “rapid and accurate detection of food-borne pathogenic microorganisms”

No.	Country/Region	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	USA	491	49.10%	13 628	77.90%	27.76
2	China	127	12.70%	139	0.79%	1.09
3	Japan	95	9.50%	1 180	6.75%	12.42
4	South Korea	66	6.60%	260	1.49%	3.94
5	France	36	3.60%	298	1.70%	8.28
6	Germany	33	3.30%	471	2.69%	14.27
7	Canada	31	3.10%	390	2.23%	12.58
8	UK	24	2.40%	136	0.78%	5.67
9	Switzerland	23	2.30%	254	1.45%	11.04
10	Netherlands	13	1.30%	215	1.23%	16.54

Table 2.2.6 Institutions with the greatest output of core patents on the “rapid and accurate detection of food-borne pathogenic microorganisms”

No.	Institution	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	REGC	25	2.50%	613	3.50%	24.52
2	HOFF	22	2.20%	242	1.38%	11.00
3	MASI	15	1.50%	61	0.35%	4.07
4	CNRS	15	1.50%	49	0.28%	3.27
5	TEXA	12	1.20%	75	0.43%	6.25
6	CALY	11	1.10%	568	3.25%	51.64
7	STRD	11	1.10%	161	0.92%	14.64
8	UYJO	10	1.00%	234	1.34%	23.40
9	UPEN	9	0.90%	301	1.72%	33.44
10	HARD	9	0.90%	69	0.39%	7.67

REGC: University of California; HOFF: F. Hoffmann-La Roche AG; MASI: Massachusetts Institute of Technology; CNRS: National Council for Scientific Research; TEXA: Texas Tech University System; CALY: CALY Technologies; STRD: Leland Stanford Junior University; UYJO: Johns Hopkins University; UPEN: University of Pennsylvania; HARD: Harvard College.

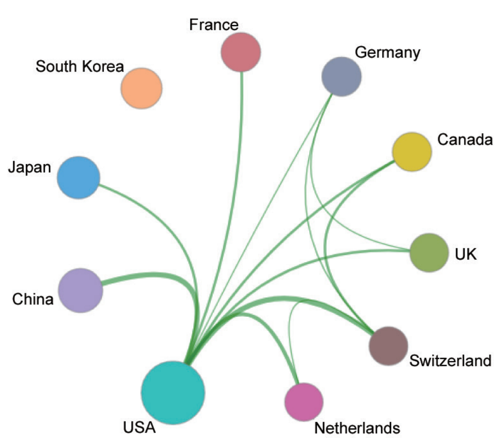

Figure 2.2.5 Collaboration network among major countries or regions in the engineering development front of “rapid and accurate detection of food-borne pathogenic microorganisms”

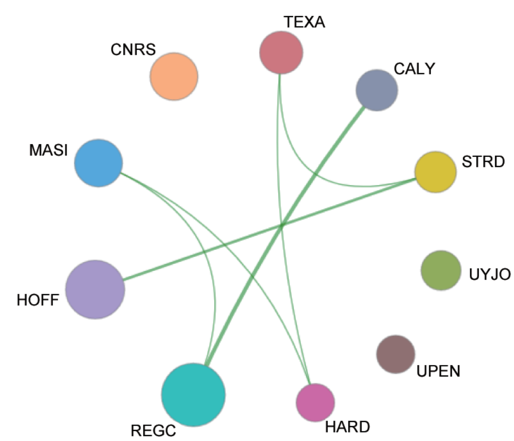

Figure 2.2.6 Collaboration network among major institutions in the engineering development front of “rapid and accurate detection of food-borne pathogenic microorganisms”

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