Research on the Development of Modern Forest Products Chemical Processing Engineering Discipline

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Abstract

From the fundamental perspective of discipline science, this paper analyzes the influence of foundational disciplines including chemistry, chemical engineering, and biochemistry on the theoretical and technological development of chemical utilization of forest plant resources over the past century, and elaborates on the origin, formation, and evolutionary history of the forest products chemical processing discipline. Building upon this foundation, it proposes that the modern forest products chemical processing engineering discipline constitutes a theoretical knowledge, methodology, and technical system that takes forest plant resources as its research object, employs chemistry and biochemistry as its disciplinary foundation, and synthesizes and prepares biomass-based new energy, chemicals, and functional materials. Finally, the paper discusses the principal challenges confronting the modern forest products chemical processing engineering discipline in both theoretical knowledge and technology.

Full Text

Origin, Formation and Development of the Discipline of Chemical Processing Engineering of Forest Products

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Abstract

This paper introduced the origin, formation and development of the discipline of chemical processing engineering of forest products by analyzing the effect of the fundamental disciplines of chemistry, chemical engineering and biology on the scientific theory and technology development in the area of chemical utilization of forestry plant resources in terms of the basic concepts of discipline science in the past more than 100 years. On these basis, we proposed the idea of the modern discipline of chemical processing engineering of forest products, and elucidated that this modern discipline is concerned with a scientific system of theories and technologies on utilization of forest plant resources by two main approaches of chemistry and bio-chemistry aiming to synthesize and prepare biomass-based energy source, chemicals and functional materials. Finally, we discussed the scientific and technological challenges that the modern discipline of chemical processing engineering of forest products is predominantly faced with in the future.

Keywords: Chemical processing engineering of forest products; Discipline; Biomass chemical engineering

The discipline of chemical processing engineering of forest products emerged from the integration of forestry with chemistry and chemical engineering. In the 1940s in China, Mr. Liang Xi, the first Minister of Forestry of the People' s Republic of China, pioneered research on the chemical processing and utilization of forest resources at Zhejiang University and Central University. In the 1950s, based on the Forest Chemistry Laboratory established by Mr. Liang Xi, Nanjing Forestry University first established a specialized research direction in chemical processing of forest products, marking the beginning of discipline construction in China and making important contributions to national economic development. In the early years of the People' s Republic, when technologies for mining and processing fossil resources such as coal and petroleum were still underdeveloped and fuels and chemicals were in short supply, this discipline played a crucial role in obtaining urgently needed chemical products from China' s abundant forest resources, and forest products chemical engineering developed into a major industry in China. Consequently, the discipline received significant attention and continued to develop. By the 1980s, China had established a discipline of chemical processing engineering of forest products focused primarily on the chemical processing and utilization of forest raw materials.

By the late 1980s and early 1990s, China had developed relatively complete industrial chains and technical systems for petroleum, coal, and natural gas chemical engineering, capable of providing abundant materials for economic construction and daily life. Petroleum, coal, and natural gas chemical engineering were characterized by large scale, high raw material utilization efficiency, and advanced integrated technologies, while forest products chemical engineering was at a distinct disadvantage in terms of production scale, product categories, and resource utilization efficiency, leading to insufficient momentum for industrial development. Therefore, from the mid-1990s to the early 21st century, the construction and development of China' s chemical processing engineering of forest products discipline stagnated, with serious brain drain greatly weakening its development capacity. However, by the late 1990s, due to the massive consumption of fossil resources like petroleum and coal and the continuous deterioration of the environment, biomass resources—the only renewable raw materials on Earth that can provide fuels and chemicals for human survival and development—received significant attention from governments and scientists worldwide, with substantial investments in research and development of biomass processing and utilization. Consequently, in the 21st century, the discipline of chemical processing engineering of forest products, which processes forest biomass resources, has ushered in unprecedented development opportunities, demonstrating tremendous vitality with continuous emergence of new theories, methods, and technologies, expanding disciplinary connotations and industrial scope, and increasing influence in scientific and technological innovation.

Against this background, fundamental questions such as the future directions and development strategies for the traditional discipline have attracted widespread attention. To date, however, consensus on these issues has not been reached, affecting the discipline' s sustained and healthy development. Internationally, there is no corresponding discipline available for reference. Based on our reflections, practices, and understanding in the discipline construction process, this paper analyzes the origin, formation, and development of the discipline from the perspective of its relationship with fundamental disciplines such as chemistry, chemical engineering, and biochemistry, and according to the basic concepts of discipline science, to provide new insights and foundations for the development of modern chemical processing engineering of forest products.

1. Origin, Formation and Development of the Discipline

1.1 Formation and Development of Wood Chemistry

In the development of natural sciences, social sciences, and technology, numerous disciplines have gradually formed. According to the history of science and technology and pedagogical perspectives, the essential attribute of a discipline is a classification of knowledge—a knowledge system composed of knowledge categories with certain logical connections. Its connotation includes three major elements: research object, research method, and scientific theoretical system. Therefore, we can consider that the origin of chemical processing engineering of forest products lies in the scientific theories, methods, and technical systems gradually formed as humans continuously explored and utilized forest resources essential to their survival and development.

Humanity' s chemical utilization of forest resources began with using heat from wood combustion for warmth, cooking, and defense, while charcoal production through wood carbonization has a history of thousands of years, playing crucial roles in human survival and development. Following the bourgeois revolution in the Netherlands in England in 1640, humanity entered modern history and the Industrial Revolution era. In capitalist society, the continuous pursuit of productivity stimulated human enthusiasm for exploring nature, developing science, and researching technology. During the 18th and 19th centuries, chemistry centered on chemical composition, structure, and properties developed rapidly, and by the early 20th century, a chemical discipline system had formed with atomic and molecular structure theory, inorganic chemistry, and organic chemistry as its main contents. Simultaneously, the development of chemistry centered on chemical changes sparked intense interest in understanding the composition and structure of naturally abundant wood. Driven by this curiosity, scientists successively identified the main chemical components of forest plant resources: cellulose, hemicellulose, and lignin. In 1719, French scientist Réaumur proposed the idea of extracting fibers from wood. In 1830, French agricultural chemist Anselme Payen first isolated cellulose by treating wood with nitric acid, with its structural formula (C H O) finally confirmed in 1913. Payen also recognized the existence of substances embedded between cellulose fibers, suggesting the possible presence of lignin. In 1857, F. Schulze named this high-carbon-content extract "lignin." Swedish scientist P. Klason, known as the "father of lignin chemistry," summarized previous research in 1897 and discovered that coniferyl alcohol reacted with bisulfite to produce sulfonates with properties similar to lignosulfonates, leading him to propose the hypothesis that lignin is a macromolecular substance closely related to coniferyl alcohol. Hemicellulose was proposed by F. Schulze in 1891 to represent polysaccharides in plants that could be extracted by alkaline solutions. The discovery and structural determination of cellulose, hemicellulose, and lignin in wood laid a solid foundation for the formation and development of wood chemistry centered on carbohydrate chemistry and lignin chemistry.

It is worth noting that the original motivation for exploring and researching wood macromolecular components, besides scientific interest in the chemical composition and structure of natural substances, was the technical need to manufacture paper for spreading human civilization. This demand 催生了 various cellulose and lignin separation technologies, such as chlorine dioxide, chlorination, and sodium chlorite methods, forming industrial pulping theories and technologies that became the source of modern pulp and paper industries. Simultaneously, cellulose separation and chemical research led to the production of cellulose derivatives including nitrocellulose, cellulose acetate, rayon, and cellophane, pioneering the modern fiber industry. Thus, it is evident that the development of wood chemical theory and technology centered on the composition and structure of forest plant resources gave birth to the pulp, paper, and cellulose industries, making important contributions to industrial progress and scientific development.

1.3 Formation of the Discipline of Chemical Processing Engineering of Forest Products

From the above analysis, through nearly a century of research and exploration, humans established wood component chemistry and non-wood component chemistry for forest resources. The author contends that forest plant resource chemistry, which takes forest plant resources as its research object, constitutes a relatively complete scientific theoretical system comprising both wood component chemistry and non-wood component chemistry. The methods and technologies for separation, purification, modification, and utilization of forest plant resource components constitute the methodological and technical system for chemical utilization of forest resources. Together, they form a knowledge-technical system with certain logical connections, establishing the discipline of chemical processing engineering of forest products. This analysis also reveals that the chemical utilization of forest resources developed gradually alongside the development and maturation of organic chemistry, physical chemistry, and polymer chemistry, as well as the advancement of organic chemical and petrochemical technologies. Therefore, the formation and development of chemical processing engineering of forest products are inseparable from the development of chemistry and chemical engineering, and can be considered as the outcome of applying chemistry and chemical engineering disciplines to the practice of forest resource utilization.

2. Connotation of Modern Chemical Processing Engineering of Forest Products

2.1 Research Object

As previously mentioned, educational theory holds that a discipline comprises research object, research method, and scientific theoretical system. For application-oriented disciplines, the technical system also constitutes a major element of disciplinary knowledge. The research object refers to the unique, irreplaceable subject or special laws of a discipline, and its determination is undoubtedly the prerequisite for clarifying disciplinary connotation and development direction. Currently, debates about the development direction of chemical processing engineering of forest products in China essentially reflect different perspectives on the research object. The traditional research object of this discipline was forest raw materials—various plant resources from forestry cultivation, harvesting, and processing, mainly including tree secretions such as rosin, shellac, and lacquer; extracts such as natural essential oils and tannins; and wood, bamboo, and their harvesting and processing residues. The research scope primarily focused on synthesis and modification of forest fine chemicals from natural resins; extraction, separation, purification, and modification of secondary metabolites from wood; wood distillation, charcoal and activated carbon preparation based on wood pyrolysis; plant hydrolysis technology mainly producing furfural; and plant fiber extraction, utilization, and modification for pulp and paper production. The emphasis was on separation, purification, and modification of small molecular components from trees, producing fine chemicals such as adhesives, flavors and fragrances, polyphenolic compounds, and industrial products like charcoal and activated carbon. This narrow interpretation once simplistically equated the discipline with raw materials and products like rosin, tannins, and activated carbon, which was detrimental to understanding its essential scientific attributes.

Viewing entire trees or bamboo forests reveals that besides the xylem of wood, bamboo, and rattan plants—whose main chemical components are cellulose, hemicellulose, and lignin—the leaves, bark, roots, secondary metabolites, physiological secretions, and oils are also important chemical components of forest plant resources. Regardless of whether these resources come from processing, they have no essential difference in chemical composition. In chemical processing, raw material composition and structure are the main factors determining processing principles, methods, technologies, and efficiency. Therefore, it is more scientific and clear to define forest plant resources as the research object of chemical processing engineering of forest products.

More importantly, defining forest plant resources as the research object facilitates leveraging the fundamental roles of chemistry and biochemistry in efficient forestry resource utilization and promotes the development of the forest products chemical industry. According to traditional interpretation, forest raw materials are resources produced during forestry cultivation, processing, and management, representing the downstream of the forestry industry—this also serves as the basis for designating chemical processing engineering of forest products as a sub-discipline of forestry engineering, viewing the forest products chemical industry merely as a branch of the forestry industry. However, from the perspective of raw material sources and chemical composition, forest raw materials are essentially the same as forest plant resources, and the theoretical knowledge and technical systems for their chemical utilization must also be identical. Therefore, artificially separating forest resources from forest plant resources and treating forest raw materials as an independent entity for research and development is scientifically unnecessary. If the research object of modern chemical processing engineering of forest products remains limited to forest raw materials or resources, the transformation and upgrading of the forest products chemical industry will encounter many conceptual obstacles, hindering its growth and the discipline’ s ability to play a central role in modern biomass science technology and emerging biomass industries.

2.2 Research Methods

The significant change in research methods for modern chemical processing engineering of forest products is the extensive application of biochemistry in the fundamental chemistry and conversion processes of forest plant resources. In the second half of the 20th century, rapid development of biochemical theories and technologies significantly promoted human understanding of various life forms and advanced bioconversion technologies and related industries. The application of biochemical theories and technologies to biomass resources including forest plant resources is determined by the composition and properties of these renewable resources.

We compared the main chemical composition and properties of biomass represented by forest plant resources with fossil resources such as coal, petroleum, and natural gas, as shown in Table 1. Compared with coal, petroleum, and natural gas, biomass raw materials contain not only carbon and hydrogen but also large amounts of oxygen, which greatly increases hydrophilicity, biocompatibility, and biodegradability, enabling bioconversion of biomass represented by forest plant resources. Therefore, chemical processing and utilization of biomass raw materials can employ not only the chemical engineering methods used for petroleum, coal, and natural gas, but also new biochemical methods. Biomass processing can extensively use non-toxic, harmless water as a reaction solvent, greatly reducing or even eliminating the need for flammable, volatile, and toxic organic solvents. Fossil raw materials such as petroleum, coal, and natural gas have poor biocompatibility and high biological toxicity, making them unsuitable for biochemical processing methods. From the current status and trends of close integration between modern chemical engineering and biochemical engineering, it is evident that traditional chemical conversion and biochemical conversion are inevitable choices for biomass resource conversion processes. From a resource perspective, chemical processing and utilization of petroleum, coal, and natural gas and that of biomass will be the two major chemical engineering systems. In the industrialization process, the era of heavy reliance on fossil resources appeared first, but the future will inevitably see coexistence of both systems or a period dominated by biomass chemical engineering. Undoubtedly, chemical processing engineering of forest products, which takes forest plant resources as its research object, will develop into a knowledge and technical system comprising both traditional chemical processing methods and biochemical processing methods. It is entirely believable that the combination of traditional chemical methods, biochemical methods, and their integration is the inevitable trend for the development of chemical processing engineering of forest products with forest plant resources as its research object.

2.3 Technical System and Supported Industries

In the disciplinary system, new research methods inevitably bring new theories and technologies, enriching and developing the connotation of chemical processing engineering of forest products. In China, the traditional discipline has established a relatively complete knowledge-technical system based on traditional chemical engineering, focusing on extraction, purification, modification, and utilization of forest raw materials to synthesize daily chemical products and industrial fine chemicals. From the perspective of basic theory and technical systems, it is an important branch of chemical engineering that has made significant contributions to China' s forest products chemical industry development, efficient forestry resource utilization, and alleviating the shortage of petroleum, coal, and natural gas resources and their processed products in the early years of the People' s Republic. With continuous development and application of traditional chemical methods and technologies, and the utilization and deepening of biochemical and bioprocess theories and technologies in forest plant resource conversion, chemical utilization technologies for both wood and non-wood components of forest plant resources are becoming increasingly rich. Since entering the 21st century, new technologies centered on chemical and biochemical conversion of forest plant resources have rapidly developed, forming a trend of converting forest plant resources into new energy, bio-based chemicals, and bio-based functional materials. This has become an important scientific and technological force supporting new energy, new medicine, and new materials fields, playing an increasingly important role in scientific and technological development and industrial support. For simplicity, the author categorizes various fine chemicals involved in traditional chemical processing engineering of forest products as bio-based chemicals. Therefore, bio-based chemicals involved in the modern discipline can be classified into various aliphatic and aromatic compounds derived from the conversion of polysaccharides and lignin, as well as various fine chemicals obtained from extraction of small molecular components from forest plant raw materials and their synthetic transformation. Thus, modern chemical processing engineering of forest products can be summarized as a theoretical knowledge, method, and technical system for synthesizing biomass energy, chemicals, and functional materials.

3. The Discipline as the Foundation and Core of Biomass Chemical Engineering

Biomass is the only renewable carbon-containing resource on Earth. Due to the massive exploitation and utilization of fossil resources like petroleum and coal and the resulting ecological environmental deterioration, the chemical utilization of biomass resources will inevitably receive high priority and attention from human society. Biomass refers to various organisms synthesized through photosynthesis. In the broad sense, biomass includes all plants, microorganisms, and animals that feed on plants and microorganisms, as well as residues and wastes from plant and animal processing and production, such as wood, crops, crop residues, wood processing residues, animal and vegetable oils, and animal manure. In the narrow sense, biomass excludes animals and mainly refers to straw from agricultural production excluding grain and fruits, trees and bamboo from forestry, agricultural and forestry wastes, processing residues, and by-products from agricultural product processing industries. In short, biomass includes not only the most primitive forms of biomass raw materials but also various secretions, residues, and wastes generated during their growth, harvesting, and processing.

The main purpose of biomass chemical processing and utilization is to develop biomass energy, biomass chemicals, and biomass functional materials, which are expected to become important industrial pillars and emerging strategic industries affecting economic development. As people gradually recognize the significance of biomass processing and utilization for socio-economic development, the research object and scope of chemical processing engineering of forest products, which focuses on chemical processing and utilization of forest plant resources such as wood and bamboo, must also change. In fact, since entering the 21st century, the research object of this discipline has expanded from forest raw materials to forest plant resources, and even to broader biomass resource categories such as crop straw and its processing residues. From a scientific and technological perspective, since straw and wood/bamboo have essentially the same chemical composition, there is no fundamental difference in their utilization, and they apply to the same knowledge and technical systems. It can be said that chemical processing engineering of forest products, which takes forest plant resources as its research object, is a knowledge and technical system for biomass chemical processing and utilization, constituting the core of biomass chemical engineering and serving as the main scientific and technological support for developing biomass energy, chemicals, and materials. Clarifying the relationship between the connotation of modern chemical processing engineering of forest products and the biomass science and technology system centered on biomass energy, chemicals, and materials, and understanding its foundational scientific and technological supporting role for emerging strategic industries such as new energy, new medicine, and new materials, will greatly accelerate the development of the modern discipline and resolve frequent difficulties encountered in disciplinary development planning.

4. Challenges in Developing Modern Chemical Processing Engineering of Forest Products

4.1 Efficient Separation Theory and Technology for Forest Plant Resources

The foundation and prerequisite for chemical utilization is mastering raw material composition and corresponding separation technologies. The development history of petrochemical engineering clearly shows that studying and mastering the various main components of petroleum resources and developing relevant theories and technologies for their effective separation gave rise to the petroleum refining industry, which is the foundation and prerequisite for petrochemical development. As is well known, in terms of composition, forest plant resources are mainly composed of biopolymers such as cellulose, hemicellulose, and lignin, except for small amounts of low molecular weight components (usually less than 10%). The low molecular weight components can be extracted from forest plant raw materials through solid-liquid separation using solvent extraction, and relatively mature chemical engineering theories and technologies can effectively achieve their separation, analysis, and further modification and utilization. These traditional chemical engineering theories and technologies were mainly developed during the chemical utilization of fossil raw materials such as coal, petroleum, and natural gas.

However, the polymer components such as cellulose, hemicellulose, and lignin in forest plant resources are non-volatile and usually insoluble in solvents. More challengingly, these biopolymers form robust cell wall structures that are non-dissolvable or meltable, making direct dispersion difficult. The cell walls contain both crystalline and amorphous regions, resulting in poor uniformity and permeability of raw materials. This creates enormous obstacles for separating and analyzing the polymer components in cell walls. Over 100 years ago, researchers invested tremendous enthusiasm and effort in analyzing and separating wood cellulose and lignin components, with the pulp and paper industry' s theories, technologies, and industrial development being the fruits of these efforts. Through long-term unremitting efforts, we have developed many separation methods for wood and other forest plant raw material components, such as acid and alkaline hydrolysis, biochemical treatment, and mechanochemical treatment, which have achieved partial separation of cellulose, hemicellulose, and lignin. However, to date, we still cannot completely or efficiently separate cellulose, hemicellulose, and lignin from wood and other forest plant resources. This is undoubtedly one of the main challenges facing chemical processing engineering of forest products. Therefore, the international community has proposed biomass refining technology, similar to the concept of petroleum refining proposed during the development of petroleum processing industries. The author believes that forest plant resource refining should include efficient separation of cellulose, hemicellulose, and lignin in cell walls, as well as extraction, separation, purification, and identification of small molecular components. The former still requires tremendous effort, while the latter is relatively mature. Both constitute the main components of the theoretical knowledge and technical system of modern chemical processing engineering of forest products.

4.2 Construction of Chemical Conversion and Green Separation Technology Systems for Forest Plant Resource Components

Among forest plant resource components, except for some small molecular components that are volatile and soluble in organic solvents, the degradation products of cellulose, hemicellulose, and lignin, as well as some small molecular components, are all water-soluble. Therefore, the chemical conversion of these substances typically uses water as the solvent, with reactions occurring in aqueous phases. Due to the lipophilicity and high volatility of petroleum, coal, and natural gas and their reaction products, their chemical conversions are mainly completed in organic solvent liquid phases and high-temperature gas phases. It is foreseeable that many chemical conversions of plant resources will occur in aqueous phases. Compared with organic synthesis and conversion processes for petroleum and other resources in organic or gas phases, aqueous-phase organic synthesis is a green synthesis technology. Catalysis is the core of chemical engineering technology, necessitating the development of catalyst systems suitable for aqueous-phase chemical conversion of biomass components and corresponding processes and equipment.

Meanwhile, the main components of forest plant resources and their chemical conversion products typically contain many oxygen atoms, resulting in poor volatility, chemical stability, and thermal stability. However, our past organic chemical separation technologies were established based on petroleum, coal, and natural gas and their conversion products, with distillation and rectification becoming the most common separation technologies due to their organic solvent basis. These separation principles and technologies cannot be applied to biomass chemical engineering in many cases, and the situation is even more complex for biochemical processing involving separation of microorganisms or enzymes. In chemical production, product separation and purification are key technologies affecting product quality and production costs. Undoubtedly, developing new separation and purification technologies suitable for chemical conversion and utilization of forest plant resources, such as membrane separation technology, is a main content for constructing the modern chemical processing engineering of forest products knowledge and technical system, and is also an inevitable choice for developing biomass chemical engineering.

4.3 High-Value Conversion Theory and Technology for Small Molecular Resources in Forest Plant Resources

Based on traditional chemical and chemical engineering technologies, long-term research has established relatively complete knowledge and technical systems for classification, properties, modification, and application of small molecular chemical components from forest plant resources. However, modification and application of these small molecular components often face competition from related small molecular chemical products synthesized from petroleum, coal, and natural gas, which typically have advantages of large scale and low cost. To better develop chemical processing engineering of forest products, it is necessary to continue exploring and developing small molecular chemical resources from forest plant resources, researching new conversion technologies to produce high-value natural fine chemicals, pharmaceutical intermediates, and natural drugs with excellent or unique properties, and using new synthesis technologies to produce natural products with unique structures and excellent properties. This will continuously inject new vitality and momentum into the development of modern chemical processing engineering of forest products.

4.4 Continuous Integration with New Theories, Technologies, and Disciplines

As analyzed previously, the traditional discipline formed and developed through the application of traditional chemical engineering theories and technologies to the conversion and utilization of forest plant resources. The deep integration of biochemical and bioprocess theories and technologies with the traditional discipline has promoted the formation and development of the modern discipline. We need not only to continue attaching great importance to the application of biochemical theories, technologies, and genetic technologies in forest plant resource conversion to improve chemical conversion levels and efficiency, but also to continuously integrate new theories and technologies from forest resources, chemistry, and biochemistry-related disciplines, and actively integrate emerging disciplines such as new energy, new materials, new medicine, and nanoscience theories and technologies. Meanwhile, we cannot ignore the impact of new engineering disciplines such as artificial intelligence technology and internet technology on modern chemical processing engineering of forest products. Only through continuous integration and discovery of new directions can the discipline maintain its vitality.

5. Conclusion

In the era of rapid development of biomass chemical engineering, the role and influence of chemical processing engineering of forest products in scientific and technological progress and socio-economic development will continue to strengthen. The modern discipline will take forest plant resources as its research object, adopt chemical and biochemical processing methods to synthesize and prepare biomass energy, chemicals, and functional materials, and continuously enrich the theoretical knowledge and technical system encompassing theories, methods, principles, processes, and equipment for biomass energy, chemicals, and functional materials, providing scientific and technological support for the development of modern new energy, new materials, new medicine, and new agriculture.

From the perspective of the discipline' s origin, formation, and development, chemical processing engineering of forest products represents a continuous process of cross-integration between fundamental disciplines such as chemistry, chemical engineering, biochemistry, and bioprocess engineering with forest resource chemical utilization. Although constructing this discipline in forestry universities and research institutes provides a good foundation for forest resource-related disciplines, it requires attaching great importance to the continuous integration of forestry with chemical processing engineering of forest products, especially emphasizing the construction of chemistry, chemical engineering, and biochemical engineering disciplines to continuously strengthen the disciplinary foundation and enhance development potential to meet the requirements of new energy, new materials, and new medicine fields. Therefore, it is understandable that research institutes with strong chemistry, chemical engineering, and biochemical engineering capabilities have already accomplished much excellent work in related areas of chemical processing engineering of forest products, significantly promoting its development. Of course, these research institutes also face issues such as insufficient understanding of forest resource chemical theories and technologies. Therefore, forestry universities constructing this discipline also need to attach great importance to cooperation and collaboration with other research institutes to propel the discipline into a new stage of development, reflecting the specific requirements for discipline construction in the era of coexistence of petroleum, coal, and natural gas chemical engineering with biomass chemical engineering.

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Note: Figure translations are in progress. See original paper for figures.