

# Construction of Carbon Fiber Industry Chain Integration Framework Based on Industrial Technology Breakthrough

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**Abstract:** Carbon fiber is a new type of high-performance fiber, which can be widely used in the fields of aerospace, machinery, building materials, transportation, sports and medical fields, thus it has an important strategic position in the national economy. Global carbon fiber demand continues to increase, but the carbon fiber industry by Japan, the United States and other developed countries monopoly. Carbon fiber industry is a highly technology and capital intensive industry. Through merger and acquisition of integrated resources, large-scale carbon fiber production enterprises can be formed to break through industrial technology, realize mass production of carbon fiber industry with stable quality and participate in international competition. Based on the analysis of the industrial chain of carbon fiber, the relationship between the integration of the industrial chain of carbon fiber and industrial technology breakthrough is sorted out, and the framework of industrial chain integration of carbon fiber is constructed based on industrial technology breakthrough from four dimensions of vertical integration, horizontal integration, lateral integration and mixed integration. Through the systematic and serialized layout of the whole industrial chain, carbon fiber enterprises can reduce costs, increase profit points, have the ability to face the competition of international giants, and reverse the difficult situation, which has great practical significance for the development of carbon fiber industry.

## 1. Introduction

Carbon fiber is a new type of high performance fiber with the features of high specific strength, high temperature resistance, abrasion resistance, and corrosion resistance, for which it is widely used in the fields of aerospace, machinery, building materials transportation, sports and medical fields, has an important strategic position in the national economy. In recent years, with the development of production technology and the expansion of application range, the demand for carbon fiber is increasing year by year. Due to the relationship between supply and demand and the double blockade of carbon fiber technology and products by developed countries, China's carbon fiber market has been in a state of constraint. Even some high-end users of carbon fiber composite materials have no raw materials to process. In addition, global demand for carbon fiber will continue to increase due to industries such as large aircraft manufacturing and clean energy.

As China's investment in carbon fiber continues to increase, China's carbon fiber production share in the world is also increasing. Carbon fiber products to stability, high-end development. Although there are 4-5 domestic carbon fiber production enterprises with a design capacity of more than 1000 tons, they lack core technical team, and have poor production process stability and process control consistency, which is unable to guarantee the quality and stability of carbon fiber products. Therefore, it is an inevitable trend to break through the industrialization technology, realize the stable production

of products and improve the utilization rate of equipment. According to statistics, currently domestic carbon fiber is mainly applied in three major fields, namely, aerospace, sports and leisure industry, while high-end application field accounted for only 4%. It is necessary to achieve technological breakthrough, form a systematic and serialized carbon fiber industry chain development mode, and break the monopoly of foreign high-end fields.

The research on carbon fiber industry needs to be strengthened. In view of the strategic position of carbon fiber and its composites, experts and scholars have carried out multi-angle research on carbon fiber, most experts focus on the overview of the current situation of carbon fiber industry development and development trend forecast, as well as the development of carbon fiber research and development technology. Domestic carbon fiber industrialization road is difficult. Therefore, the realization of carbon fiber industrialization path needs experts and scholars to carry out research according to industrial development theory, put forward targeted solutions. However, at present, there is still a lack of research in this aspect, so it is urgent to enrich the research results in this aspect to provide theoretical support and theoretical basis for the development path of domestic carbon fiber industry.

This paper studies the integration and construction of carbon fiber industrial chain, adjusts the industrial structure, provides reference for the development of commercial decisions of carbon fiber enterprises or potential carbon fiber enterprises, and provides basis for the government and relevant management departments to formulate targeted policies. Technology industrialization can be divided into two dimensions, namely, industrialization of the potential industrial technology innovation and commercialization of the existing industry technology innovation achievements. [1] The technical breakthrough of strategic emerging industries are divided into four stages, that is, peripheral architecture breakthrough, peripheral technology penetration, key technology breakthrough and industrial structure restructuring and upgrading. [2] The innovative path was proposed based on the destructive innovation perspective. [3] It was put forward that the integration of enterprise technology and products should be improved, and 3-4 enterprises should be supported in the development process of China's carbon fiber industry. [4] The concept of the whole industry chain should be adopted according to the success of Japan Toray Company. [5] The carbon fiber industry was studied from the perspective of GERT network based on input-and-output table. [6] Some scholars from abroad have studied carbon fiber industry from the perspective of general introduction and technology breakthrough. [7-10]

The existing literature is of great significance to understand the integration of carbon fiber industry chain and also provides reference. However, there is a lack of research on the mechanism of carbon fiber industrial chain integration to promote industrial technological innovation, industrial upgrading and international competitiveness improvement. Among the few literatures on the integration of carbon fiber industry chain, there are many descriptive literatures and insufficient theoretical analysis. There lacks systematic research about the carbon fiber industry chain, and insufficient attention is paid to the formulation and implementation of strategic policy, technology breakthrough, innovation and policy environment construction.

Although some scholars put forward by the necessity and feasibility of carbon fiber industry chain integration of technology innovation, these studies did not studied on the carbon fiber industry chain co-opetition relationships between different subjects as well as the specific integration models. In-depth study is needed on the scientific problems of China's carbon fiber industrial chain integration, the integration patterns, and the benefits of carbon fiber industry chain and auxiliary chain quantitative and reasonable allocation, which will discussed in this research.

## **2. Carbon Fiber Industry Chain**

Carbon fiber industry chain mainly includes the upstream carbon fiber production, carbon fiber, intermediate materials, composite materials, and downstream carbon fiber application. The precursor is the key factor in the preparation of carbon fiber. The preparation process of carbon fiber precursor includes polymerization and spinning, and the spinning technology can be divided into wet spinning,

dry spinning, dry spraying and wet spinning and melt spinning. Carbon fiber can be obtained by preoxidation, carbonization, sizing and other processes, in which preoxidation is the key step to prepare carbon fiber. The intermediate product of resin matrix composites, in which carbon fibers are impregnated and molded, is called prepreg. Carbon fiber prepreg is an important intermediate material connecting carbon fiber and composite material. Its quality directly affects the quality of carbon fiber products. Carbon fiber composite materials are obtained by hand paste and injection technology, hot press tank forming technology, molding technology, winding forming technology, extrusion forming technology and other processes. Finally, carbon fiber is widely used in aerospace, industrial applications and sports and leisure fields.

The main carbon fiber production countries or regions include Japan, the United States, European countries and China's Taiwan. Japan has been a global leader in carbon fiber since the 1960s. Japan and America account for most of the world's carbon-fiber production. The international market for carbon fiber is dominated by Japanese and American companies. In recent years, the carbon fiber industry is rising in emerging countries such as Turkey, South Korea, Saudi Arabia and China. At present, the world's main manufacturers of tow carbon fiber are Toray, Toho, Mitsubishi, Hexcel and Cytec. Taiwan's Formosa plastics and Turkey's Aksa are also growing. Major manufacturers of large tow carbon fibers include Aldila of the United States, Toho, Toray of Japan, and SGL of Germany. In general, Japan has an obvious advantage in the production of small tow carbon fiber, while the United States has a prominent advantage in the production of large tow carbon fiber.

Carbon fiber industry chain has the following features. Firstly, technology is the key. A popular statement in the international carbon fiber industry can summarize the value added process of the carbon fiber industrial chain: from raw materials to carbon fiber, the price changes from 1 to 3; when carbon fiber is processed into composite materials, the price increases from 3 to 10. Carbon fiber, in other words, would be commercially worthless if it were not converted into composites. According to the data of Cytec industry research, the cost composition of carbon fiber is roughly as follows: 51% of raw silk, 16% of oxidation, 23% of carbonization, 4% of surface sizing and 6% of winding. According to the application cost composition of carbon fiber composite material of Boeing aircraft given by experts of Boeing Company, carbon fiber material only accounts for 8%-20% of the cost, and technology and process manufacturing account for more than 80% of the cost. Zoltek's experts have made similar claims about the use of carbon-fiber composites in cars, suggesting that carbon fiber only accounts for about 20% of the cost of carbon-fiber composites. So the industrialization of carbon fiber on the one hand to reduce the cost of raw materials, on the other hand to control the cost of manufacturing process. As early as 1996 by the United States advanced civil aircraft new materials professional committee proposed to continue to develop low-cost manufacturing process.

Secondly, the carbon fiber industry has a long production process with many process control points. The production of carbon fiber involves the polymerization reaction, textile, carbonization, infiltrating agent and other surface treatment of raw silk production, and has higher requirements on the downstream resin industry, mold design and molding process and other application links of composite materials. There are more than 3,000 manufacturing process control points in a 1000-ton carbon fiber production line. So it's a long way from breakthrough lab production to quantitative production.

Thirdly, carbon fiber industry needs large investment amount, and return cycle is relatively long. Carbon fiber products have high technology content, large technical bottleneck, complex manufacturing process, and need equipment, experience, technology, talent, capital and other comprehensive investment. For instance, Toray, the world's leading carbon fiber company, has suffered losses for more than two decades, and Herschel of America has been restructured after two bankruptcies. This is especially true of Jiangsu Hengshen group in China. In the past ten years, it has invested 4.6 billion Yuan (RMB) accumulatively, and it costs hundreds of thousands of yuan per day to operate one production line, and more than one million yuan for five production lines.

Finally, carbon fiber industry has high industry concentration. Japan is the world's leading producer of carbon fiber, represented by companies such as Toray, Toho and Mitsubishi. Major manufacturers in other regions include Zoltek and Hexcel in the United States, SGL in Germany and

FPC in Taiwan. At present, there are nearly 40 domestic enterprises producing carbon fiber, and Jiangsu, Shandong and Jilin provinces have become the hubs of carbon fiber industry in China. Take Jiangsu province as an example. In 2016, there were 24 enterprises with carbon fiber quantitative production in China, with the theoretical capacity of 25,000 tons, among which Zhongfu Shenying and Jiangsu Hengshen were 6,200 tons and 5,000 tons respectively, accounting for more than 60% of the total production capacity in China.

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### **3. Current Situation of China's Carbon Fiber Industry**

Since 2014, China's demand for carbon fiber has grown at an average annual rate of 13 percent to 20 percent, according to the China chemical industry information center. More than 50 percent of carbon fiber composites will be used on the CR929, China's first large wide-body passenger plane.

China's carbon fiber industry has experienced continuous investment from scratch and the arduous process of tackling difficulties. At present, it has achieved the domestic scale production of T300 grade carbon fiber and the industrial production of T700 grade carbon fiber. T800 grade carbon fiber has achieved a breakthrough in industrial production technology. However, whether it is raw material development or downstream application, there are some bottlenecks that need to be broken. It is understood that China's carbon fiber market, especially the high-performance carbon fiber market is still under the double dilemma of intensified blockade abroad and severe shortage of domestic supply, "loss – less production – loss of market – loss" the vicious cycle has not been completely solved. At present, there are more than 100 enterprises engaged in the research and production of carbon fiber and its composite material products and equipment manufacturing in China. Advanced equipment and high-end carbon fiber prepreg mainly rely on imports. Downstream market demand and other conditions have not been very good improvement. It is urgent for the industry to break through the key technology of engineering preparation of high-performance carbon fiber, establish the industrial chain structure of carbon fiber preparation and application with Chinese characteristics, and realize the completely independent application of carbon fiber in the fields of transportation, energy, construction, automobile, aerospace and other fields.

Carbon fiber plays a very important role in the country's future new materials program. "Made in China 2025" proposes that by 2020, the technical maturity of domestic high-strength carbon fiber and its composite materials will reach level 9, realizing large-scale application in the fields of automobiles and high-tech ships. So, how to reverse the passive situation of industrial development and achieve the goal smoothly? Experts agreed that carbon fiber industry structure adjustment, technological innovation and industrial upgrading should be accelerated, foreign technology monopoly should be broken, independent innovation should be taken, and carbon fiber industrialization should be accelerated.

### **4. Relationship between Carbon Fiber Industrial Chain Integration and Industrial Technology Breakthrough**

Industrial chain is a very important concept in industrial economics. Due to the forward and backward extension of the relationship between supply and demand, input and output, various enterprises in the industrial chain form a network structure and form a self-organizing system

together with other related institutions that can provide basic resources for industrial development. Industrial technological breakthrough is a systematic and collaborative technological innovation activity in the industrial system, led by the industrial core enterprises, with the participation of relevant enterprises, based on the diffusion of generic technologies, the integration of old and new technologies, and characterized by key technological breakthroughs.

In this study, the integration of carbon fiber industrial chain refers to the integration in a broad sense. As long as one manufacturer in the industrial chain can directly or indirectly control the decisions of another manufacturer, we regard this phenomenon as integration, which includes vertical integration, horizontal integration, and the combination with the auxiliary chain of carbon fiber industrial chain. Vertical integration mainly through improving the integrity of carbon fiber industrial chain, extension force and coupling degree; Horizontal integration expands the scale of enterprises by means of peer cooperation or mergers and acquisitions to improve the market advantages of important core enterprises; Lateral integration focuses on the integration with different nature of the industrial chain, the multi-functional expansion of the industrial chain, to avoid the waste of resources and vicious competition caused by the isomorphism of the industrial chain.

Industrial chain integration is dominated by the core enterprises in the industrial chain. Driven by capital and knowledge, it adjusts, combines and integrates the current situation of the separation of industrial chain, so as to finally improve the competitive advantage of enterprises and realize the optimal allocation of resources in the industrial chain. The subject of industrial chain integration is the enterprise, and the object is the factor of production, including capital, knowledge, resources and so on. In the process of industrial chain integration, the government formulates industrial policies and creates an environment to guide the direction of industrial chain integration. The market optimizes enterprise relations through free competition and improves the operation efficiency of the whole industrial chain. This paper discusses the relationship between the carbon fiber industry chain integration and industrialization and technological breakthroughs, builds carbon fiber industry chain integration framework. A carbon fiber industrial chain integration is divided into the main chain of the carbon fiber industry chain integration of subsystems, and two auxiliary chain integration of subsystems. Combined with the domestic and international successful cases, the integration of industrial chain is formulated from the four dimensions of the vertical integration, horizontal integration, lateral integration and hybrid integration and meanwhile industrialization of technological breakthrough effect is studied.

According to the characteristics and evolution process of carbon fiber industry chain, this paper makes the following definition of carbon fiber industry chain integration: the main body of the carbon fiber industry chain are carbon fibre enterprises, and the capital, information, technology, talent and knowledge as regarded as the subjects. According to the inherent logic of carbon fiber industry chain, the carbon fiber industry integration can be conducted from three dimensions of longitudinal, transverse and lateral integration, in order to realize the industrial chain integration from dot to line and from line to surface, from the surface to the evolution of the breakthrough, thus to improve the production elements configuration, and finally to realize the global optimization of the industrial chain.

Industrial technology breakthrough and industrial chain integration are mutually promoting and promoting each other. On the one hand, industrial technological breakthroughs improve enterprises ability to integrate resources and improve their position in the industrial chain, thus providing possibilities for the redefinition, transformation, adequacy, perfection and upgrading of industrial structure. On the other hand, the integration of industrial chain can affect the integration of internal technology, equipment, personnel and other factors, improve the external cooperation relationship of enterprises, improve cooperation efficiency, promote the absorption of internal knowledge, strengthen the flow of external resources, so as to promote technological breakthroughs in the industrialization of carbon fiber. In essence, the development of strategic emerging industries is the evolution process of emerging technology industrialization. In the process from emerging technology to industrialization development, there are three stages, namely, key technology breakthrough, technology standardization and technology commercialization. The key technological breakthrough

in the carbon fiber industry is the internal driving force of the development of the carbon fiber industry, technical standardization is the key to the sustainable development of the carbon fiber industry, and technology commercialization is the cornerstone of technology evolution to production. The integration of carbon fiber industry chain can be divided into horizontal integration, vertical integration, lateral integration, and the hybrid integration of the three integration modes, which can promote the key technology breakthrough of carbon fiber production, accelerate the process of technology standardization and commercialization. After the technological breakthrough of carbon fiber industrialization, new industrial technologies can be generated, and the emergence of new industrial technologies will further promote the development of a new industrial chain. The interactive relationship between industrial chain integration and industrialization technology breakthrough is shown in the following figure. In this paper, from the perspective of industrial chain integration promoting industrialization technology breakthrough, break through the bottleneck of industrialization technology hinders the development of carbon fiber industry in China.

## **5. Carbon Fiber Industry Chain Integration Framework**

Industrial chain is a very important concept in industrial economics. Due to the forward and backward extension of the relationship between supply and demand, input and output, various enterprises in the industrial chain form a network structure and form a self-organizing system together with other related institutions that can provide basic resources for industrial development. Industrial technological breakthrough is a systematic and collaborative technological innovation activity in the industrial system, led by the industrial core enterprises, with the participation of relevant enterprises, based on the diffusion of generic technologies, the integration of old and new technologies, and characterized by key technological breakthroughs.

In this study, the integration of carbon fiber industrial chain refers to the integration in a broad sense. As long as one manufacturer in the industrial chain can directly or indirectly control the decisions of another manufacturer, we regard this phenomenon as “integration”, which includes vertical integration, horizontal integration, and the combination with the auxiliary chain of carbon fiber industrial chain. Vertical integration mainly focuses on improving the integrity of carbon fiber industrial chain, extension force and coupling degree; Horizontal integration expands the scale of enterprises by means of peer cooperation or mergers and acquisitions to improve the market advantages of important core enterprises; Lateral integration focuses on the integration with different nature of the industrial chain, the multi-functional expansion of the industrial chain, to avoid the waste of resources and vicious competition caused by the isomorphism of the industrial chain.

According to the characteristics and evolution process of carbon fiber industry chain, this paper makes the following definition of carbon fiber industry chain integration: carbon fiber industry chain nodes namely enterprise are regarded as the main body, the capital, information, technology, talent and knowledge are taken as the subject, and the whole integration process is dominated by carbon fiber enterprises, according to the inherent logic of carbon fiber industry chain, thus improve the production elements configuration, finally realizes the global optimization of the industrial chain. [11] Industrial technology breakthrough and industrial chain integration are mutually promoting and promoting each other. [12] On the one hand, industrial technological breakthroughs improve enterprises' ability to integrate resources and improve their position in the industrial chain, thus providing possibilities for the redefinition, transformation, adequacy, perfection and upgrading of industrial structure. On the other hand, the integration of industrial chain can affect the integration of internal technology, equipment, personnel and other factors, improve the external cooperation relationship of enterprises, improve cooperation efficiency, promote the absorption of internal knowledge, strengthen the flow of external resources, so as to promote technological breakthroughs in the industrialization of carbon fiber.

On the basis of previous literature review on the integration of emerging industrial chain and carbon fiber industrial chain, based on the development status of carbon fiber in China and the current difficulties, this paper constructs the framework of the integration of carbon fiber industrial chain in

China, as shown in the following figure. China's carbon fiber industry chain integration system consists of one main chain integration subsystem and two side chain integration subsystems. The main body of the integrated main chain consists of upstream, midstream and downstream enterprises of carbon fiber. The integration mode of the main chain is divided into vertical integration of the industrial chain and horizontal integration of the industrial chain. The two integrated side chains are the basic chain of equipment industry composed of equipment enterprises, and the basic chain of intellectual industry composed of institutions such as universities, scientific research institutes, key laboratories, guilds and intermediaries. The side chain integration mode is mainly the lateral integration of the main chain and auxiliary chain of the carbon fiber industrial chain. In the process of cultivating carbon fiber industry in China, facing the double pressure of foreign market squeeze and technology blockade, it is difficult for China's carbon fiber industry chain to realize the optimal allocation of resources independently. Based on the development status of carbon fiber industry at home and abroad and the important role of carbon fiber in military and civil use, the government needs to step in to speed up the improvement of carbon fiber industry chain in China. Government can give financial support, can also be a series of policy system to regulate and guide the carbon fiber industry development, to provide targeted fiscal and taxation support policy, financial credit policy, intellectual property rights (IPR) protection policy, talent training, etc., the coupling effect, give full play to the government policies to form a good policy environment conducive to the development of carbon fiber industry, as is shown in figure 1.

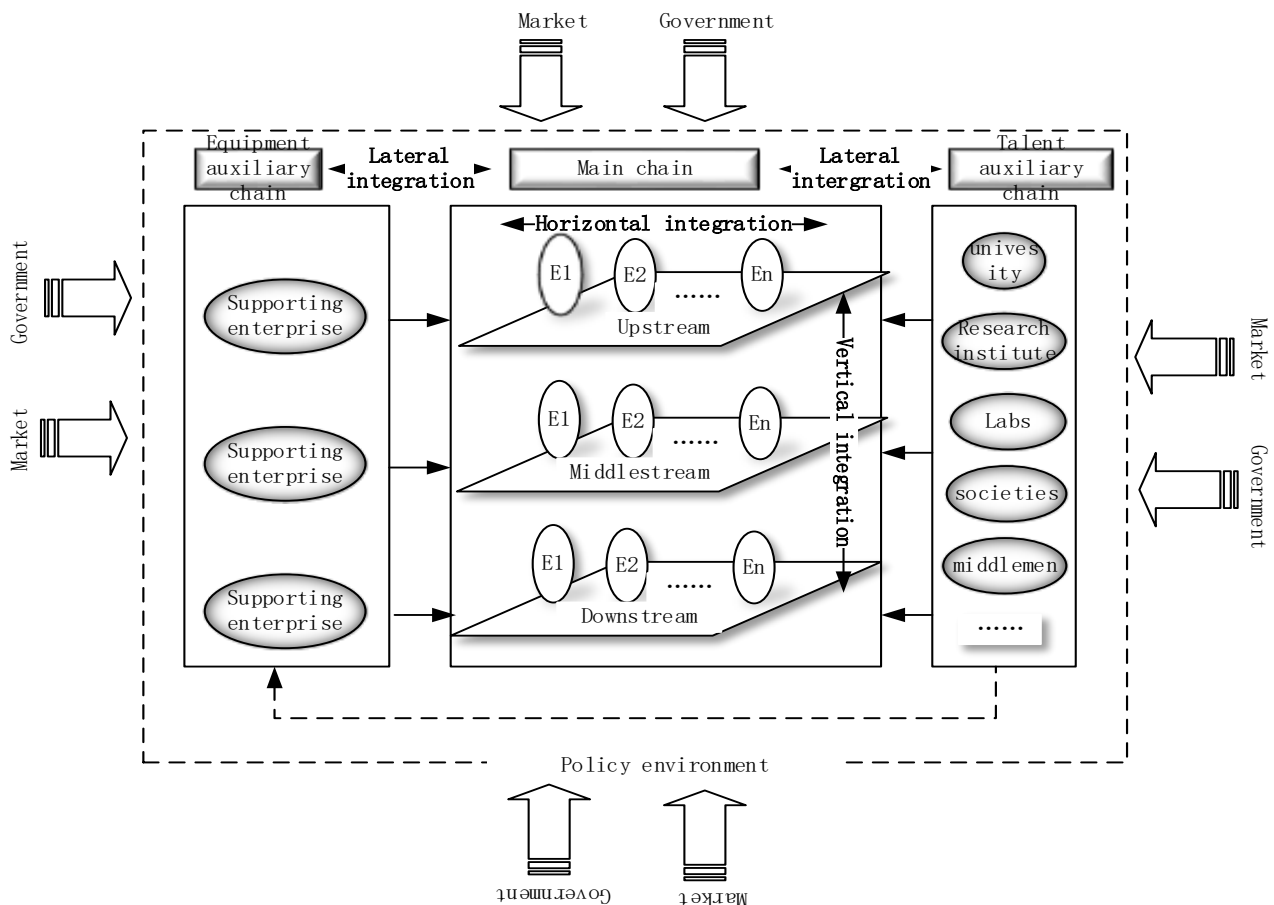


Figure 1. Carbon fiber industry chain integration framework

## 6. Conclusion

Industrial technology breakthrough is a systematic project with high investment risk. Under the background of globalization, enterprises need to break through technology by seeking external innovative resources. Industrial chain integration is an important means of external technology

introduction. Based on the current case of carbon fiber industrial chain integration, this paper analyzes the effect of industrial chain integration on industrial technology breakthrough from four dimensions of vertical integration, horizontal integration, lateral integration and comprehensive integration.

The integration of carbon fiber industry chain accelerates the technological breakthrough process of carbon fiber industrialization. Industrial chain integration is essentially a process of breaking the constraint of resource flow space. Through internal knowledge absorption and external knowledge flow, knowledge sharing and knowledge transformation can be realized, which is the key factor for industrial technology breakthrough. The integration of carbon fiber industry chain has a positive impact on the accumulation and optimization of enterprise's technology, equipment, personnel and other resources through the integration of technology and market, and finally promote the breakthrough of carbon fiber industrialization technology. Carbon fiber industrial chain integration can also integrate universities, research institutes, equipment enterprises, financial institutions, the government and other environmental resources, accelerate the flow of external resources for the development of carbon fiber industry, so as to provide intellectual, financial, basic equipment, development environment and other aspects of support for carbon fiber industrialization technology breakthrough. In short, industrial chain integration is an effective way for enterprises to improve their technical capabilities, which also plays a positive role in promoting the technical capabilities of the whole industrial chain.

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