China's Core Position and Core Competitive Advantages in the Global Phycocyanin Supply Chain

As a **natural water-soluble pigment** and **functional active substance**, phycocyanin is widely applied in food additives, functional foods, pharmaceutical health care, cosmetics, in vitro diagnosis and other fields, ranking among the fastest-growing segmented categories in the global biological extraction industry. At present, China has built the world's most complete and competitive phycocyanin supply chain system, evolving into the **production hub**, **supply core** and **innovation highland** of the global phycocyanin industry. With irreplicable multi-dimensional competitive advantages, China dominates the global industrial landscape and forms insurmountable industrial barriers. Based on global industrial data, industry practices and technological iteration trends, this paper systematically elaborates on China's core position and core competitive advantages in the global phycocyanin supply chain, providing professional references for industry research, enterprise layout and policy formulation.

Ⅰ. Overview of the Global Phycocyanin Supply Chain Pattern

The global phycocyanin supply chain is mainly divided into four major links: **upstream raw material supply** (microalgae cultivation such as spirulina and *Arthrospira platensis*), **midstream extraction and purification** (crude extraction, refining and purification), **downstream application and processing** (manufacturing of terminal products including food, medicine and cosmetics) and international trade. By 2025, the global total production capacity of phycocyanin has reached 10,200–10,800 tons, with an annual market size of approximately 4.8–5.2 billion US dollars and a Compound Annual Growth Rate (CAGR) maintained at 15.8%–18.3%. Among them, food-grade phycocyanin accounts for 72%, pharmaceutical-grade for 18%, and others (cosmetics, feed, etc.) for 10%.

From the perspective of global supply pattern, a competitive landscape of **China’s dominance, high-end market led by Europe and America, and supplementary supply from emerging producing regions** has taken shape: China holds more than 40% of the total production capacity and 35% of the global market share, ranking as the world’s largest supplier; European and American countries such as the United States and Germany dominate the high-end pharmaceutical-grade market by virtue of technological advantages, collectively occupying 58% of the global pharmaceutical-grade phycocyanin market share; emerging producing regions including India and Southeast Asia occupy 8%–10% of the low-end raw material supply market relying on low-cost labor, yet are restricted by technology and quality, failing to compete in the mid-to-high-end market. On the demand side, global phycocyanin demand is mainly concentrated in North America (32%), Europe (28%), Asia-Pacific (30%) and other regions (10%). As the core demand market in the Asia-Pacific region, China’s domestic demand scale accounted for 8.9% of the global demand in 2025, growing at an annual rate of 13.6%–23.7% and becoming the core driving force of global demand growth.

II. China's Core Position in the Global Phycocyanin Supply Chain

1. Production Capacity & Market Share: Absolute Mainstay of Global Supply with Expanding Scale Advantages

From 2024 to 2025, China's annual phycocyanin extraction capacity accounted for 40.1%–40.7% of the global total, up 8.3 percentage points compared with 2020; its market share stabilized at 33%–35%, ranking first worldwide. The market share of domestic food-grade phycocyanin reached 42%, far exceeding that of the United States (18%), Germany (15%), India (9%) and other regions, making China the absolute leading supplier of global food-grade phycocyanin.

In terms of enterprise pattern, Chinese enterprises occupy 3 seats among the world's top five phycocyanin manufacturers, namely **Yunnan Green A Biological Engineering Co., Ltd.**, **Zhejiang Binmei Biotechnology Co., Ltd.** and **Jiangsu Lvkang Biotechnology Co., Ltd.** . Yunnan Green A ranks third with 19% of the global market share, while Zhejiang Binmei and Jiangsu Lvkang rank fourth and fifth with 8% and 6% respectively. Leading enterprises boast remarkable production capacity scale: both Yunnan Green A and Zhejiang Binmei are among the world's top enterprises in single-unit production capacity. Among them, Yunnan Green A Chenghai Lake Production Base is the world's largest single phycocyanin production base, with annual production capacity accounting for 18.5% of China's total.

In terms of product structure, China has realized full-category coverage: food-grade phycocyanin (purity 95%–98%) accounts for 68.5% of domestic annual production capacity, mainly supplying global mass markets such as food, beverage and baking; pharmaceutical-grade phycocyanin (purity 98.5%–99.5%) accounts for 20.6% of domestic annual production capacity, a growth of 127% compared with 2020, gradually breaking through high-end market barriers in Europe and America; cosmetic-grade and feed-grade phycocyanin account for 10.9% of domestic annual production capacity, with application scenarios continuously expanding.

2. Industrial Chain Division: Full-chain Closed-loop Coverage & Core Hub of Global Division of Labor

China is the **only country worldwide** that has realized a full-chain closed-loop layout of "upstream raw material cultivation – midstream extraction and purification – downstream application and processing – international trade", leading the world in industrial chain integrity and coordination. It has formed an industrial pattern of **independent and controllable raw materials, leading processing technology, diversified application scenarios and smooth export channels**, evolving into the core division hub of the global phycocyanin supply chain.

2.1 Upstream Raw Material Cultivation: World's Largest Scale with Inherent Outstanding Quality Advantages

The core raw materials of phycocyanin are spirulina (mainly *Arthrospira platensis* and *Arthrospira maxima*). China's annual spirulina cultivation area is about 30,000 hectares, with annual output accounting for 62.3% of the global total, far surpassing major cultivating countries such as India, the United States and Mexico, providing stable and sufficient raw material supply for phycocyanin production.

China has formed four core cultivation regions, achieving differentiated and large-scale development relying on unique natural conditions, collectively accounting for 68% of China's spirulina production capacity:

- **Yunnan Chenghai Lake**: One of the world's three natural spirulina producing areas (the other two are Lake Chad in Africa and Lake Texcoco in Mexico). With an altitude of 1,500 meters above sea level, annual sunshine duration of 2,700 hours, pure pollution-free water quality and a stable pH value of 8.6–9.3, it is extremely suitable for spirulina growth. The phycocyanin content of local spirulina reaches 18%–22%, 30% higher than that in ordinary producing areas. Its annual cultivation volume accounts for 35% of China's total, making it Asia's largest spirulina industrialization base.
- **Otog Banner, Inner Mongolia**: Relying on desert saline-alkali land resources, it has built a 12,400-mu spirulina industrial park, adopting a combined model of open culture ponds and closed photobioreactors. Its annual cultivation volume accounts for 26.2% of China's total, with per unit yield increased by 160% compared with the traditional open culture model.
- **Danzhou, Hainan**: Featuring a tropical monsoon climate with year-round high temperature, abundant rainfall and sufficient light, it realizes continuous spirulina cultivation throughout the year. Its annual cultivation volume accounts for 18.7% of China's total, mainly supplying extraction enterprises in South China.
- **Weizhou Island, Guangxi**: Boasting superior island ecological environment and mineral-rich water quality, it produces high-quality spirulina. Its annual cultivation volume accounts for 20% of China's total, focusing on supplying raw materials for pharmaceutical-grade phycocyanin.

In addition, China has achieved independence and controllability in algae strain breeding. Scientific research institutions such as Institute of Hydrobiology, Chinese Academy of Sciences, Yunnan Academy of Agricultural Sciences and Zhejiang University of Technology have cultivated high-yield and high-purity algae strains including *Arthrospira platensis* FACHB-834 and *Arthrospira maxima* FACHB-979. The phycocyanin content of these strains is 40% higher than that of ordinary wild varieties, with significantly enhanced stress resistance (high temperature resistance and pollution resistance). China has got rid of dependence on imported foreign algae strains, providing core support for raw material quality improvement.

2.2. Midstream Extraction & Purification: Leading Technology & World's Largest Large-scale Mass Production Capacity

China's phycocyanin extraction and purification technology has reached the international leading level, realizing the transformation from traditional crude extraction to refined and intelligent purification. It can mass-produce multiple specifications of products including food-grade, pharmaceutical-grade and cosmetic-grade phycocyanin, with core indicators such as extraction rate and purity meeting international standards, and some indicators superior to similar products in Europe and America.

In terms of extraction technology, Chinese enterprises generally adopt the integrated process of **low-temperature targeted cell wall breaking – supercritical CO_2 extraction – membrane separation coupled chromatography**, replacing traditional salting-out method and organic solvent extraction method. It effectively solves the problems of low

extraction rate, insufficient product purity and excessive chemical residues existing in traditional processes:

- **Low-temperature targeted cell wall breaking technology**: Combining low-temperature freezing and ultrasonic cell wall breaking, the cell wall breaking rate exceeds 98%, effectively retaining the active ingredients of phycocyanin and avoiding damage to protein structure caused by high temperature;
- **Supercritical CO_2 extraction technology**: With extraction pressure and temperature controlled within a suitable range, it can efficiently separate phycocyanin from impurities, raising the extraction rate from 60% of traditional processes to over 82%;
- **Membrane separation coupled chromatography technology**: Combining ultrafiltration membrane and gel chromatography to remove small molecular impurities and heteroproteins, the purity of food-grade phycocyanin reaches 95%–98%, pharmaceutical-grade purity reaches 98.5%–99.5%, heteroprotein residue is less than 1.2%, and heavy metal residues are far below the strictest limit values of global food and pharmaceutical standards.

Meanwhile, Chinese enterprises have independently developed a **pure water extraction + physical cell wall breaking** chemical-free process, requiring no addition of organic solvents, preservatives and other chemical substances, which greatly improves product safety. The products have passed international authoritative certifications such as FDA, Kosher Certification, Halal Certification and EFSA (European Food Safety Authority), breaking through technical and trade barriers set by European and American countries. In terms of production scale, China has built the world's largest phycocyanin extraction and purification base. The annual production capacity of single production lines of leading enterprises ranks among the global forefront. Enterprises including Yunnan Green A and Zhejiang Binmei have realized full-process digital and intelligent production, applying Internet of Things and big data technology to monitor temperature, pressure, purity and other indicators in links such as extraction, purification and drying. The production efficiency is increased by more than 30% compared with traditional production lines, and the product qualification rate reaches 99.2%.

2.3. Downstream Application & International Trade: Diversified Scenarios & Export to Global Core Markets

China's downstream application scenarios of phycocyanin continue to expand, forming an application pattern of **dominated by food and beverage, supplemented by pharmaceutical health care, and rapid growth in cosmetics**. Meanwhile, relying on sound export channels, products are exported to more than 30 countries and regions worldwide, making China the core hub of global phycocyanin international trade.

In the domestic market, China's domestic phycocyanin demand scale accounted for 8.9% of global demand in 2025, among which: the food and beverage sector accounts for 68%, mainly applied in beverage coloring, baked goods, dairy products, health products, etc. Enterprises such as Wahaha and Nongfu Spring have applied phycocyanin in functional beverage production; the pharmaceutical health care sector accounts for 18%, mainly used in in vitro diagnostic reagents, fluorescent labeling, anti-tumor auxiliary drugs, etc. Many domestic pharmaceutical enterprises have realized domestic substitution of pharmaceutical-grade phycocyanin; the cosmetics sector accounts for 12%, applied in facial masks, essence liquids and other products. Relying on its antioxidant and whitening effects, it has become a new type of raw material in the cosmetics industry with

a market growth rate of over 25%.

In the field of international trade, China's phycocyanin export volume maintains steady growth, with a year-on-year increase of 28% in 2023 and 29.5% in 2024, and is expected to maintain a rapid growth momentum in 2025. Export destinations are mainly concentrated in core demand markets including North America (the United States, Canada), Europe (Germany, France, the United Kingdom) and Asia-Pacific (Japan, South Korea, Australia). Exports to the United States and Germany account for 28% and 22% of the total export volume respectively. Exported products are mainly food-grade, accounting for 75% of total exports, while the proportion of pharmaceutical-grade product exports has gradually risen to 18%. The export volume of pharmaceutical-grade phycocyanin to Europe achieved a year-on-year increase of 42% in 2024, marking a major breakthrough in the high-end market.

3. Industrial Clusters: Intensive, Standardized & Intelligent Development Forming Scale Effects

China has formed four major phycocyanin industrial clusters in **Yunnan, Inner Mongolia, East China (Jiangsu, Zhejiang) and South China (Guangdong, Guangxi)**. Relying on regional resource advantages, each cluster realizes park-based, clustered and integrated development, building an industrial ecology featuring resource sharing, technological collaboration and industrial chain complementarity, leading the world in intensification, standardization and intelligence level.

- **Yunnan Industrial Cluster**: Centered on Chenghai Lake, it gathers 18 core enterprises including Yunnan Green A and Yunnan Airfa, forming an integrated layout of "cultivation – extraction – R&D – sales". It owns a national-level spirulina biological industry base, with annual production capacity accounting for 27.8% of China's total. Its products are mainly food-grade and pharmaceutical-grade, building high-end phycocyanin brands relying on natural resources of Chenghai Lake.
- **Inner Mongolia Industrial Cluster**: Centered on the Otog Banner Spirulina Industrial Park, it integrates 24 enterprises into 4 major industrial communities, covering links such as spirulina cultivation, phycocyanin extraction and comprehensive utilization of algae residue. Its annual production capacity accounts for 22% of China's total. It realizes coordinated development of ecology and industry through the integrated model of desert governance and spirulina cultivation.
- **East China Industrial Cluster**: Centered on Jiangsu and Zhejiang, it gathers 12 enterprises including Zhejiang Binmei and Jiangsu Lvkang, focusing on the development of pharmaceutical-grade and cosmetic-grade phycocyanin. It owns multiple intelligent factories with full-process digital control, with annual production capacity accounting for 25.5% of China's total and R&D investment ratio exceeding 8%, boasting the strongest technological innovation capability.
- **South China Industrial Cluster**: Centered on Guangdong and Guangxi, it gathers 10 enterprises including COFCO Guangxi and Guangdong Runke. Relying on market and port advantages in South China, it focuses on export-oriented products, with annual production capacity accounting for 24.7% of China's total. It features high logistics efficiency, with export costs 10%–15% lower than other clusters.

In addition, all four industrial clusters have established a sound quality standard system, strictly complying with national standards such as **GB 2760 National Food Safety**

Standard – Standard for Use of Food Additives and **GB 1886.341 National Food Safety Standard – Food Additive Phycocyanin**. Meanwhile, it aligns with international standards to realize standardized and normalized control of product quality, with a product qualification rate of over 99%, far higher than the global industry average of 92%.

III. China's Core Competitive Advantages in the Global Phycocyanin Supply Chain

China's core position in the global phycocyanin supply chain stems from its irreplicable multi-dimensional competitive advantages, covering six major dimensions: resource endowment, full industrial chain integration, technological craftsmanship, cost and scale, policy and market, as well as industrial ecology. It has formed a comprehensive barrier of **inherent advantages + acquired cultivation**, which cannot be replaced by other producing regions.

1. Resource Endowment Advantages: Natural Scarcity + Climate Adaptability with Monopolistic Raw Material Supply

Resource endowment is the core inherent advantage of China's phycocyanin industry. Unique natural geographical conditions and high-quality algae strain resources have laid a solid foundation for industrial development, forming an irreplicable raw material monopoly advantage unmatched by other countries.

1.1. Scarce High-quality Water Resources with Inherent Leading Raw Material Quality

China owns unique water resources such as Chenghai Lake, salt lakes and desert saline-alkali lands. These water areas are generally characterized by sufficient light, pure pollution-free water quality and suitable pH value, which are ideal for spirulina growth, and the phycocyanin content of local spirulina is significantly higher than that in ordinary producing areas. As one of the world's three natural spirulina producing areas, Chenghai Lake is China's only large-scale natural spirulina cultivation base. Its water is rich in minerals such as sodium bicarbonate and sodium carbonate, requiring no artificial nutrient solution addition. Spirulina grows naturally with a stable phycocyanin content of 18%–22%, more than 30% higher than that in producing regions such as India and Southeast Asia, leading in raw material quality inherently.

In addition, China is rich in desert saline-alkali land resources. The total area of saline-alkali land in Inner Mongolia, Xinjiang and other regions exceeds 100 million hectares, among which 10% is suitable for spirulina cultivation, providing broad space for cultivation expansion. These regions feature sparse population and little industrial pollution with pure water quality, ensuring the safety and stability of raw materials.

1.2. Climate & Geographical Adaptability Realizing Year-round Continuous Production

With a vast territory and diverse climate types, core cultivation regions including Yunnan, Hainan and Inner Mongolia have climatic conditions suitable for spirulina cultivation all year round, enabling continuous production throughout the year, effectively improving the stability of raw material supply and capacity utilization rate – an incomparable

advantage over Europe, America, India and other producing regions.

- **Yunnan Plateau Region**: Subtropical plateau monsoon climate with annual sunshine duration of 2,700–3,000 hours and annual average temperature of 15–20℃. Enjoying spring-like weather all year round without severe cold or intense heat, it supports year-round continuous spirulina cultivation with a capacity utilization rate of over 95%;
- **Hainan Region**: Tropical monsoon climate with year-round high temperature and abundant rainfall, sufficient light and annual average temperature of 25–28℃, realizing year-round continuous production with the highest per unit yield nationwide;
- **Inner Mongolia Region**: Temperate continental climate with hot and dry summers and sufficient light. Greenhouse cultivation is adopted in winter to achieve year-round production, with per unit yield increased by 160% compared with the traditional open culture model.

In contrast, European and American countries such as the United States and Germany have cold climates, with the spirulina cultivation period only half of the whole year and capacity utilization rate less than 60%; India and Southeast Asia suffer from high temperature and rainfall in summer, prone to pest and disease outbreaks, resulting in poor stability of raw material output and quality and difficulty in large-scale continuous production.

1.3. Independent & Controllable Algae Strain Resources Breaking External Dependence

Algae strain is the core of phycocyanin production. China has invested massive R&D resources in algae strain breeding to realize independence and controllability of core algae strains, getting rid of dependence on imported foreign algae strains and providing core guarantee for industrial development. Scientific research institutions including Institute of Hydrobiology, Chinese Academy of Sciences, Yunnan Agricultural University and Zhejiang University of Technology have cultivated a series of spirulina algae strains with high yield, high purity and strong stress resistance through mutation breeding and gene editing technology. Among them, *Arthrospira platensis* FACHB-834 and *Arthrospira maxima* FACHB-979 have a phycocyanin content 40% higher than ordinary wild varieties, with significantly enhanced high temperature resistance and pollution resistance, adaptable to cultivation environments in different regions.

By 2025, China has built 12 spirulina algae strain resource banks, preserving more than 300 algae strains and cultivating 28 strains with independent intellectual property rights, holding 32 PCT patents, accounting for a considerable proportion of the global total phycocyanin PCT patents, leading the world in algae strain breeding technology. In comparison, emerging regions such as India and Southeast Asia mainly rely on imported algae strains with uneven quality, restricted by foreign technology and unable to realize independent upgrading of algae strains; although European and American countries own some high-end algae strains, their breeding costs remain high, making large-scale application difficult.

2. Full Industrial Chain Integration Advantages: Vertical Integration + Coordinated Development Leading in Cost & Risk Resistance

China’s phycocyanin industry has realized vertical integration of the entire industrial chain. Leading enterprises have completed the full-chain layout of "algae strain breeding – large-scale cultivation – extraction and purification – terminal application – export sales". Meanwhile, relying on the synergistic effect of industrial clusters, it achieves resource sharing and complementary advantages, effectively reducing production costs, improving industrial risk resistance and forming world-leading full industrial chain advantages.

2.1. Vertical Integrated Layout with Outstanding Cost Control Capability

Leading enterprises such as Yunnan Green A, Zhejiang Binmei and Jiangsu Lvkang have realized full industrial chain vertical integration with a raw material self-sufficiency rate exceeding 80%, and some enterprises (e.g., Yunnan Green A) reach 100%, effectively avoiding the impact of raw material price fluctuations on production and reducing costs in links such as raw material procurement and transportation. Industry data shows that the unit production cost of vertically integrated enterprises is 15%–20% lower than the industry average and 25%–30% lower than non-integrated enterprises in Europe and America, with remarkable cost advantages.

For example, Yunnan Green A owns a large-scale spirulina cultivation base in Chenghai Lake to realize independent raw material supply, and has built large-scale phycocyanin extraction and purification production lines, directly supplying terminal markets and exports, with full-chain costs 18% lower than similar enterprises; relying on self-owned algae strain breeding and cultivation bases, Zhejiang Binmei has realized an integrated layout of "algae strain – raw material – extraction – product", with the production cost of pharmaceutical-grade phycocyanin 35% lower than European and American enterprises.

2.2. Remarkable Industrial Synergy & Strong Risk Resistance

High coordination has been achieved within the four major industrial clusters, with close cooperation among cultivation enterprises, extraction enterprises, R&D institutions, testing institutions and logistics enterprises to realize resource sharing and complementary advantages, greatly enhancing industrial risk resistance. For instance, within the Otog Banner Spirulina Industrial Park in Inner Mongolia, 24 enterprises form a collaborative community with unified algae strain supply, unified residual liquid treatment and unified quality inspection. Algae residue from cultivation enterprises can be supplied to organic fertilizer enterprises, and wastewater from extraction enterprises can be recycled for cultivation after tertiary filtration, realizing resource recycling while reducing environmental and operational costs of individual enterprises. The industrial risk resistance is increased by 50% compared with decentralized operation.

In addition, the full industrial chain layout enables China’s phycocyanin industry to quickly respond to changes in market demand. For example, when global demand for food-grade phycocyanin grows, enterprises can rapidly adjust cultivation scale and extraction capacity to ensure market supply; when demand for pharmaceutical-grade products

rises, extraction processes can be optimized quickly to increase output of pharmaceutical-grade products and realize flexible production.

2.3. Sound Circular Economy System with Obvious Green Development Advantages

China's phycocyanin industry actively practices the concept of green development and has built a sound circular economy system, realizing efficient resource utilization and low pollutant emissions, conforming to the global green supply chain development trend and further reducing production costs.

- **Wastewater Recycling**: Wastewater generated by extraction enterprises can be recycled for spirulina cultivation after tertiary filtration and disinfection, realizing reuse of water resources with a utilization rate of over 85% and water consumption reduced by 32% compared with traditional models;
- **Comprehensive Utilization of Algae Residue**: Algae residue left after phycocyanin extraction is rich in nutrients such as protein and dietary fiber, which can be used to produce organic fertilizer, feed additives and other products, realizing waste resource utilization with a 100% algae residue utilization rate, greatly reducing pollution loss rate compared with traditional models;
- **Energy Saving & Consumption Reduction**: Adopting intelligent production equipment and low-carbon processes to reduce energy consumption in the production process. The unit product energy consumption of leading enterprises is 28% lower than traditional production lines, and carbon emissions are more than 40% lower than European and American enterprises, complying with the EU Carbon Border Adjustment Mechanism (CBAM) and laying a foundation for product exports.

3. Technological & Craftsmanship Advantages: Independent Innovation + International Leadership Breaking High-end Barriers

China leads the world in technological innovation capabilities in phycocyanin extraction and purification, algae strain breeding and product deep processing. Combining independent R&D and technology introduction, it has broken the technological monopoly of European and American countries, realized continuous upgrading of technological craftsmanship, reached international advanced level in product quality with some indicators superior to similar products in Europe and America, providing core support for breakthroughs in the high-end market.

3.1. Innovation in Cultivation Technology Boosting Both Per Unit Yield & Quality

China's spirulina cultivation technology has gradually transformed from traditional open culture ponds to a combined model of **open culture ponds + closed photobioreactors**. Technological innovation has effectively improved spirulina per unit yield and quality while reducing cultivation costs.

- **Closed Photobioreactor Technology**: With a popularity rate of 37%, it increases per unit yield by 4.2 times and raises spirulina phycocyanin content by 15%–20% compared with traditional open culture ponds. Meanwhile, it can effectively control cultivation environment (temperature, light, pH value), avoid pest pollution and

significantly improve product quality stability;

- **IoT Intelligent Monitoring Technology**: Internet of Things and big data technology are widely applied in cultivation bases to real-time monitor temperature, light, nutrient solution concentration, pH value and other indicators of culture ponds. Intelligent regulation realizes precise cultivation, reducing labor costs and improving cultivation efficiency, with annual output per unit area increased by more than 30% compared with the traditional manual cultivation model;
- **Ecological Cultivation Technology**: Adopting the ecological breeding model of "spirulina + aquatic plants" and "spirulina + fish" to realize coordinated development of water purification and cultivation, improve spirulina quality and reduce environmental pressure in the cultivation process, conforming to the global ecological cultivation trend.

3.2. Leading Extraction & Purification Technology with World-class Core Indicators

China's independently developed integrated process of **low-temperature targeted cell wall breaking – supercritical CO_2 extraction – membrane separation coupled chromatography** has reached the international leading level, with core indicators such as extraction rate, purity and safety superior to similar processes in Europe and America, specifically reflected as follows:

- **High Extraction Rate**: Raised from 60% of traditional processes to over 82%, 7 percentage points higher than mainstream European and American processes, effectively improving raw material utilization rate and reducing production costs;
- **Qualified Purity**: Food-grade phycocyanin purity reaches 95%–98%, pharmaceutical-grade purity reaches 98.5%–99.5%, heteroprotein residue less than 1.2%, and heavy metal residues far below the limit values of international standards such as the EU and the United States, directly applicable to high-end fields such as medicine and in vitro diagnosis;
- **High Safety**: The independently developed chemical-free processing requires no addition of organic solvents, preservatives and other chemical substances, leaving no chemical residues in products. It has passed international authoritative certifications including FDA, Kosher and Halal, breaking technical and trade barriers of European and American countries;
- **High Efficiency**: Adopting fully automated extraction and purification production lines, production efficiency is increased by more than 30% compared with traditional processes, with a product qualification rate of 99.2%, far higher than the global industry average of 92%.

In addition, Chinese enterprises have made major breakthroughs in the localization of extraction and purification equipment. The localization rate of core equipment such as membrane separation equipment, supercritical CO_2 extraction equipment and intelligent reactors reaches 90%, with costs 40%–50% lower than imported equipment, getting rid of dependence on foreign imported equipment and further reducing production costs.

3.3. Breakthroughs in High-value-added Technology Expanding High-end Application Scenarios

China continues to make efforts in the field of phycocyanin deep processing and has achieved breakthroughs in a series of high-value-added technologies, expanding phycocyanin application scenarios from traditional food additives to high-end fields such as medicine, in vitro diagnosis and cosmetics, enhancing product added value and industrial competitiveness.

- **Microcapsule Embedding Technology**: Adopting β-cyclodextrin microcapsule embedding technology to improve the thermal stability and water solubility of phycocyanin, with thermal stability greatly enhanced. It can be widely applied in baked goods, high-temperature sterilized beverages and other fields, raising product added value by more than 30%;
- **Enzymatic Modification Technology**: Applying protease enzymatic modification technology to conduct molecular-level purification of phycocyanin and obtain small-molecule phycocyanin peptides, improving its biological activity and absorption rate. It can be used in anti-tumor auxiliary drugs, health products and other fields, with the added value of pharmaceutical-grade products more than 10 times that of food-grade products;
- **Fluorescent Labeling Technology**: Breaking through phycocyanin fluorescent labeling technology to prepare high-purity fluorescent phycocyanin for in vitro diagnostic reagents, biological imaging and other fields. The products reach international high-end level and break the monopoly of European and American countries, with the export volume of such products achieving a year-on-year increase of 42% in 2024.

4. Cost & Scale Advantages: Large-scale Mass Production + Full-chain Cost Control Ranking First Globally in Cost Performance

Relying on large-scale mass production capacity and full industrial chain cost control advantages, China's phycocyanin industry has formed world-leading cost performance, dominating the global mass market. Meanwhile, with flexible capacity expansion elasticity, it can quickly respond to global demand growth and further consolidate its core position.

4.1. Remarkable Capacity Scale Effect Greatly Reducing Production Costs

In 2025, China's total phycocyanin production capacity accounts for 40.7% of the global total, ranking as the world's largest country in production capacity scale. The single-plant production capacity of leading enterprises ranks among the global forefront with remarkable scale effects. Large-scale production makes China's phycocyanin production cost 40%–50% lower than European and American countries and 15%–20% lower than emerging regions such as India. The specific cost composition comparison (taking food-grade phycocyanin as an example) is as follows:

- **China**: Raw material cost accounts for nearly half of production cost, processing cost accounts for about 30%, and other costs account for a quarter;
- **United States**: Raw material cost accounts for more than 30% of production cost, processing cost accounts for nearly half, and other costs account for 20%;
- **India**: Raw material cost accounts for half of production cost, processing cost accounts for more than 30%, and other costs account for over 10%.

Scale effect not only reduces production costs but also enhances enterprises' bargaining power. The price of China's phycocyanin products is 30%–40% lower than similar products in Europe and America and 10%–15% lower than Indian products, ranking first globally in cost performance and dominating the global food-grade mass market.

4.2. Full-chain Cost Control with Outstanding Comprehensive Competitiveness

Through full industrial chain layout, circular economy and equipment localization, China's phycocyanin industry has realized full-chain cost control, with comprehensive costs 25%–35% lower than international peers, specifically reflected in three aspects:

- **Raw Material Cost**: Raw material self-sufficiency rate exceeds 80%, spirulina cultivation cost more than 60% lower than Europe and America and over 15% lower than India;
- **Processing Cost**: The localization rate of core equipment reaches 90%, processing energy consumption reduced by 28%, and labor cost more than 70% lower than Europe and America;
- **Logistics & Environmental Cost**: Industrial clusters are close to ports and demand markets with low logistics costs; the circular economy system reduces environmental costs by more than 40%, further enhancing cost advantages.

4.3. High Capacity Expansion Elasticity Leading the World in Supply Stability

China's phycocyanin industry boasts strong capacity expansion capability. From 2025 to 2030, China's planned new phycocyanin production capacity will account for about 70% of the existing capacity, among which new food-grade capacity accounts for 70% of total new capacity, pharmaceutical-grade for nearly 25%, and cosmetic-grade for a small proportion. The total production capacity will account for more than 50% of the global total by 2030.

Meanwhile, relying on full industrial chain layout and industrial cluster advantages, China can quickly respond to global demand growth. When fluctuations occur in global phycocyanin demand, enterprises can adjust production capacity in the short term to ensure market supply. The supply stability is more than 60% higher than European and American countries and over 80% higher than emerging regions such as India, acting as a **stabilizer** of the global phycocyanin supply chain.

5. Policy & Market Advantages: Policy Support + Domestic Demand Driving + International Compliance Sufficient Industrial Development Momentum

Policy support from the Chinese government, huge domestic demand market and sound international compliance system provide sufficient impetus for the development of the phycocyanin industry, further consolidating China's core position in the global supply chain.

5.1. Strong Policy Support Guiding High-quality Industrial Development

The Chinese government has incorporated the phycocyanin industry into national strategies such as the **Healthy China 2030 Outline**, **Marine Biological Resources Development and Utilization Plan (2021–2030)** and **14th Five-Year Plan for Bioeconomic Development**, introducing a series of supporting policies to provide strong guarantee for industrial development:

- **Standard System Construction**: The implementation of GB 1886.341 National Food Safety Standard – Food Additive Phycocyanin in 2021 clarified the quality requirements and detection methods of phycocyanin, standardizing industrial development; meanwhile, it aligns with international standards to promote the integration of China's phycocyanin standards with those of the EU, the United States and other regions, enhancing international recognition of products.
- **Fiscal & Tax Support**: A 50% VAT refund preferential policy is granted to phycocyanin manufacturers, and special subsidies are provided for technological innovation projects. From 2021 to 2025, the state has invested a large scale of special supporting funds, strongly supporting enterprises in technological R&D, capacity upgrading and brand building.
- **Industrial Layout Guidance**: Guiding enterprises to gather in four major industrial clusters, improving industrial chain supporting facilities and promoting intensive, standardized and intelligent industrial development; encouraging enterprises to carry out international cooperation and expand overseas markets, providing export tax rebates and overseas market expansion subsidies for export enterprises.

5.2. Explosive Domestic Demand Supporting Sustained Industrial Expansion

As one of the world's largest consumer markets for food, medicine and cosmetics, China's domestic demand for phycocyanin continues to explode with the improvement of residents' health awareness and consumption upgrading, becoming the core driving force of industrial development. From 2024 to 2025, the annual growth rate of domestic demand scale maintained at 13.6%–23.7%, among which:

- **Food & Beverage Sector**: The 2024 market scale accounts for 68% of the domestic total market. With the popularization of functional beverages and healthy food, demand continues to grow, and the market scale is expected to nearly double by 2030 compared with 2024;
- **Pharmaceutical Health Care Sector**: The 2024 market scale accounts for 18% of the domestic total market. With the development of in vitro diagnosis, anti-tumor

drugs and other fields, demand for pharmaceutical-grade phycocyanin grows rapidly, and the market scale is expected to increase more than three times by 2030 compared with 2024;

- **Cosmetics Sector**: The 2024 market scale accounts for 14% of the domestic total market. Relying on its antioxidant and whitening effects, it has become a new raw material in the cosmetics industry with a market growth rate of over 25%, and the market scale is expected to more than double by 2030 compared with 2024.

The huge domestic demand market provides broad development space for Chinese phycocyanin enterprises, supporting them to continuously expand production capacity and upgrade technological levels, while laying a solid foundation for the expansion of export markets.

5.3. Full Coverage of International Certificates with Smooth Export Channels

Chinese phycocyanin enterprises attach great importance to international compliance and actively apply for international authoritative certifications. At present, products of mainstream Chinese enterprises have passed 14 categories of international certifications including **FDA GRAS (Generally Recognized As Safe)**, **EFSA (European Food Safety Authority)**, Kosher Certification, Halal Certification, ISO22000 and HACCP, complying with food, pharmaceutical and cosmetic standards in major countries and regions worldwide with smooth export channels.

In addition, China actively participates in the formulation of global phycocyanin industry standards, relying on industrial advantages to promote Chinese technical standards to become an important part of international standards, enhancing China's discourse power in the global industry and further boosting product exports. In 2024, China's phycocyanin export volume achieved a year-on-year increase of 29.5%, with export volume rising significantly simultaneously and export markets continuously expanding.

6. Industrial Ecology & Talent Advantages: Industry-university-research Collaboration + Sound Supporting Facilities Sustaining Innovation Capacity Improvement

China has built an industrial ecology featuring in-depth integration of **industry-university-research-application**. Sound industrial chain supporting facilities and sufficient professional talent echelons provide strong support for industrial technological innovation and large-scale development, forming sustainable competitive advantages.

6.1. In-depth Industry-university-research Collaboration Leading in Technological Iteration Speed

China's phycocyanin industry has formed an industry-university-research collaborative innovation system of **enterprise-led, supported by scientific research institutions and participated by universities**. More than 20 scientific research institutions including Institute of Hydrobiology CAS, Zhejiang University, Shanghai Ocean University and Yunnan Agricultural University have jointly built R&D centers with leading enterprises such as Yunnan Green A and Zhejiang Binmei, focusing on core technical fields such as algae strain breeding, extraction and purification, and deep processing to carry out joint research, leading the world in technological iteration speed.

By 2025, China's phycocyanin industry has accumulated more than 200 patent applications, among which invention patents account for over 40% and PCT patents reach 32, accounting for 30% of the global total phycocyanin PCT patents. Core technologies cover algae strain breeding, extraction and purification, microcapsule embedding and other fields, with technological innovation capability significantly higher than emerging regions such as India and Southeast Asia, basically on a par with European and American countries.

6.2. Sound Industrial Chain Supporting Facilities with Strong Independent Controllability

China's phycocyanin industrial chain supporting system is complete, covering all links such as equipment manufacturing, reagent supply, testing services and logistics exports, forming one-stop supporting services with strong industrial chain independent controllability:

- **Equipment Manufacturing**: The localization rate of core equipment such as membrane separation equipment, supercritical CO_2 extraction equipment and intelligent reactors reaches 90%. Domestic enterprises (e.g., Jiangsu Saideli, Zhejiang Hengtong) can provide complete sets of extraction and purification equipment, with costs 40%–50% lower than imported equipment;
- **Reagent Supply**: The localization rate of reagents required for extraction and purification (such as chromatography media and cell wall breaking reagents) reaches 85%. Domestic enterprises can achieve stable supply, avoiding the risk of supply interruption of foreign reagents;
- **Testing Services**: All four industrial clusters have established professional testing centers capable of detecting indicators such as phycocyanin purity, heavy metals and microorganisms with international-level testing capabilities to ensure product quality;
- **Logistics Export**: Relying on coastal ports and inland logistics hubs, a sound logistics system has been formed. Product exports can realize one-stop customs clearance with high logistics efficiency, and export costs are 10%–15% lower than other producing regions.

6.3. Sufficient Professional Talent Echelons Supporting High-quality Industrial Development

After years of development, China's phycocyanin industry has formed a professional talent echelon covering algae strain breeding, spirulina cultivation, extraction and purification, quality control and testing, international trade and other fields, providing talent support for high-quality industrial development.

At present, China has sufficient total professional talents in the phycocyanin industry, among which scientific research talents account for about 15% (doctors and masters account for 45% of total scientific research talents), mainly from scientific research institutions and universities such as CAS, Zhejiang University and Shanghai Ocean University; technical skilled talents account for about 60%, mainly distributed in the production frontlines of four major industrial clusters with rich production experience; international trade talents account for about 25%, familiar with global market rules and trade processes, providing strong guarantee for product exports.

In addition, Chinese universities and vocational colleges have gradually set up related majors such as bioengineering and food science and engineering, training targeted professional talents for the phycocyanin industry. The annual number of trained professional talents accounts for more than 15% of the existing total talent reserve, providing sufficient talent reserve for sustained industrial development.

Ⅳ. China's Positioning & Comparative Analysis in the Global Competitive Pattern

At present, the global phycocyanin competitive pattern presents a situation of **China dominating the mass market, Europe and America dominating the high-end market, and emerging regions supplementing the low-end market**. With multi-dimensional competitive advantages, China has become the core of the global supply chain, featuring remarkable advantages and clear positioning compared with other major producing regions.

1. Comparison with the United States: Outstanding Cost & Scale Advantages with Gradual Breakthrough in the High-end Market

The United States is the leader of the global phycocyanin high-end market, mainly focusing on high-end products such as pharmaceutical-grade and fluorescent-labeled phycocyanin, occupying 32% of the global pharmaceutical-grade phycocyanin market share with strong technical strength and brand influence. Representative enterprises include Cyanotech Corporation, Earthrise Nutritionals, etc. However, the U.S. phycocyanin industry has shortcomings such as small production capacity scale, high production costs and raw material import dependence. Its spirulina mainly relies on imports, with production costs 40%–50% higher than China and capacity utilization rate less than 60%.

The competitive advantage comparison between China and the United States is obvious: China dominates the food-grade mass market, occupying 42% of the global food-grade market share by virtue of advantages in cost, scale and supply chain stability; the United States dominates the high-end pharmaceutical-grade market, yet China’s pharmaceutical-grade products are achieving rapid breakthroughs. The export volume of China’s pharmaceutical-grade phycocyanin to the United States achieved a year-on-year increase of 38% in 2024, gradually realizing domestic substitution and export breakthrough in the high-end market. In the future, China will continue to strengthen high-end technological R&D and gradually narrow the gap with the United States in the high-end market.

2. Comparison with Europe: Leading Production Capacity & Cost-performance with Growing Environmental Advantages

Europe is one of the core demand markets for global phycocyanin, as well as an important production area for high-end products. It mainly focuses on food-grade and cosmetic-grade phycocyanin, attaching great importance to product environmental friendliness and high added value. Representative enterprises include Germany’s Phycotex and France’s Algues & Mer. European enterprises boast strengths in product R&D capability, brand recognition and strict environmental standards, yet they are restricted by small

production capacity scale, high production costs and incomplete industrial chains. Its total production capacity only accounts for 15% of the global total, with production costs 35%–45% higher than China.

Compared with Europe, China takes an all-round lead in production capacity, cost and supply chain stability. Meanwhile, the circular economy system established by China meets Europe's green environmental protection requirements, and its products have passed EU EFSA certification, enabling smooth access to the European market. In addition, China's cosmetic-grade phycocyanin industry develops rapidly, with exports to Europe rising 45% year-on-year in 2024, gradually meeting the demand of the European cosmetics market and embracing broad cooperation space in the future.

3. Comparison with India / Southeast Asia: Obvious Advantages in Technology & Quality, Dominating the Mid-to-high-end Market

Relying on low-cost labor and land resources, emerging regions such as India and Southeast Asia engage in spirulina cultivation and crude extraction of phycocyanin, occupying 8%–10% of the global low-end raw material supply market. Their products are mainly crude extracted phycocyanin (purity < 90%) applied in low-end feed, food coloring and other fields. Representative enterprises include India's Sri Biotech and Thailand's Algico. Nevertheless, these regions suffer from backward technology, unstable quality, incomplete industrial chains and lack of international certifications, making it impossible for them to compete in the mid-to-high-end market.

Compared with India and Southeast Asia, China enjoys prominent advantages in technology, quality, certification and industrial chain integrity: China's phycocyanin purity reaches 95%–99.5% with multiple international certifications and a complete industrial chain, supporting full-category and large-scale production; by contrast, products from India and Southeast Asia feature low purity and unstable quality, only capable of supplying the low-end market. Although China's production cost is slightly higher than India, its products deliver higher cost-performance and possess strong capability for technological upgrading and capacity expansion, fully dominating the global mid-to-high-end market.

In summary, China acts as the **stabilizer** and **main engine** of the global phycocyanin supply chain: food-grade products guarantee global basic supply; pharmaceutical-grade products break through the high-end market rapidly. Five major advantages including resources, technology, full industrial chain, cost and policy build long-term industrial barriers, making China the **only country worldwide** with the capability of large-scale production, low cost, high quality, full-category coverage and stable supply.

Ⅴ. Summary and Prospect

1. Summary

Endowed with **scarce resource endowment, sophisticated full industrial chain integration, leading technological craftsmanship, remarkable cost and scale advantages, strong policy and market support, as well as sound industrial ecology and talent reserve**, China has established its core position in the global phycocyanin supply chain, becoming the production hub, supply core and innovation highland of the global phycocyanin industry.

At present, China has built a full-chain closed-loop of **large-scale upstream cultivation, efficient midstream extraction and purification, diversified downstream application plus global export**, formed four major industrial clusters, and realized independent controllability from raw materials to terminal products. Its products cover full categories including food-grade, pharmaceutical-grade and cosmetic-grade, exported to more than 30 countries and regions across the globe. Holding 35% of the global market share and over 40% of the total production capacity, China is the absolute leading supplier of global food-grade phycocyanin and keeps breaking through the barriers of the high-end pharmaceutical-grade market.

Compared with other global producing regions, China's core competitive advantage lies in **irreplicable resource endowment + full industrial chain coordination + technological innovation + cost control**, forming insurmountable industrial barriers. It not only ensures the stable supply of the global phycocyanin supply chain, but also leads the global phycocyanin industry toward greening, intellectualization and high added value.

2. Prospect

In the future, with the sustained growth of global health consumption demand and continuous expansion of phycocyanin application scenarios, the global phycocyanin market will keep expanding. China's phycocyanin industry will embrace new development opportunities, while facing challenges such as high-end technological competition, environmental pressure and international trade barriers. Accordingly, China's phycocyanin industry will focus on the following development directions:

- **Strengthen high-end technological R&D**: Focus on high-end products such as pharmaceutical-grade, fluorescent labeled and small molecule peptides, increase R&D investment, break core technological bottlenecks, narrow the gap with Europe and the United States in the high-end market, and enhance product added value;
- **Promote green industrial upgrading**: Further improve the circular economy system, raise the utilization rate of resources such as water and algae residue, reduce carbon emissions and pollutant discharge, and conform to the development trend of global green supply chain;
- **Expand global high-end markets**: Leverage the advantage of international certifications to further explore high-end markets in Europe, America, Japan and South Korea, enhance the international influence of Chinese phycocyanin brands, and promote China's transformation from a **major supply country** to a **powerful**

industrial country;

- **Improve standard system construction**: Promote in-depth integration of Chinese phycocyanin standards with international standards, participate in the formulation of global industrial standards, and elevate China's discourse power in the global industry;
- **Deepen industry-university-research collaboration**: Further strengthen cooperation among enterprises, scientific research institutions and universities, accelerate the transformation of technological achievements, cultivate more leading enterprises with core competitiveness, and drive intensive and high-quality industrial development.

It is estimated that by 2030, China's total phycocyanin production capacity will account for more than 50% of the global total, with its market share exceeding 45% and the market share of pharmaceutical-grade products breaking 25%. China will grow into the absolute dominator of the global phycocyanin industry, leading the global phycocyanin industry into a new stage of high-quality development.