Development History of Phycocyanin Industry

Part I: A Tribute to the Pioneers

Phycocyanin is a natural blue functional protein extracted from cyanobacteria such as *Arthrospira platensis* (Spirulina platensis). It integrates dual properties of natural coloration and biological activity, standing as the only natural blue pigment on earth that can be mass-produced and applied in food. As the core light-harvesting pigment-protein for cyanobacterial photosynthesis, it features stable molecular structure and bright color, alongside multiple physiological functions including antioxidant, anti-inflammatory, immunomodulatory and hepatoprotective effects.

Benefiting from iterative progress in Spirulina cultivation and bio-extraction technologies, phycocyanin has undergone a century of fundamental research, more than half a century of technological breakthroughs, and nearly two decades of market cultivation. A complete high-end industrial chain has been established, covering targeted strain breeding, raw material pretreatment, low-temperature targeted extraction, membrane separation and chromatographic refining, activity standardization, and end-product application. Widely deployed in food colorants, health food, cosmetics & personal care, biomedicine, pet health and other sectors, phycocyanin serves as a benchmark product in the global natural pigment and functional raw material track, characterized by high safety, high added value and robust growth potential.

The advancement of the phycocyanin industry is inseparable from long-term dedication and innovative breakthroughs by global algal researchers, biochemistry specialists, extraction process engineers, separation & purification technologists, safety assessors, standard-setters and practitioners across the full industrial chain. We hereby pay sincere tribute to all scientific research teams, professional institutions and industrial enterprises engaged in fundamental research, structural analysis, process development, safety evaluation, standard framework construction, formulation development and global market promotion of phycocyanin.

In compliance with industrial competition rules and corporate privacy protection principles, specific enterprise rankings are omitted in this section. We extend special recognition to domestic and overseas enterprises that have made outstanding contributions to the development of this industry.

List of Honorees

(I) Core Scientists & Researchers (Chronologically ordered by research achievements)

1. ***G. T. Engelmann (Germany):***

   In the late 19th century, he first discovered blue photosynthetic pigments in cyanobacteria and verified their participation in energy transfer during photosynthesis,

laying the foundational groundwork for the discovery of phycocyanin.

2. ***A. N. Glazer (USA):***

   During the 1960s–1970s, he systematically analyzed the molecular structure of phycocyanin, clarified the composition of α and β subunits as well as chromophore binding mechanisms, and established theories linking phycocyanin spectral properties to biological activity, delivering core theoretical support for subsequent purification and functional research.

3. ***T. Watanabe (Japan):***

   In the 1970s, he pioneered research on crude extraction processes for Spirulina phycocyanin, developed basic technical routes of water extraction and salting-out, realized small-scale preparation of phycocyanin for the first time, and initiated industrialization exploration.

4. ***H. Takahashi (Japan):***

   In the 1980s, he optimized phycocyanin extraction and purification technologies, developed chromatographic refining workflows to produce high-purity phycocyanin, systematically validated its antioxidant and anti-inflammatory activities, and defined its functional positioning.

5. ***M. Weber (Germany):***

   In the 1990s, he led multi-dimensional toxicological and sensitization assessments of phycocyanin, completed safety certification for high-purity products, and facilitated its entry into premium health markets across Europe and North America.

6. ***Joint FAO/WHO Expert Committee on Food Additives (JECFA):***

   In the late 1990s, it formulated universal specifications governing heavy metal limits, solvent residual thresholds and microbial criteria for phycocyanin, establishing baseline standards for global trade.

7. ***Researcher Qin Song (Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences):***

   Starting from the 1990s, he dedicated himself to structural, functional and industrial research on phycobiliproteins (including phycocyanin), uncovered molecular mechanisms of antioxidant activity, overcame technical bottlenecks in mass purification, and drove the transition of domestic phycocyanin from laboratory samples to industrial-scale production.

8. ***Professor Zhang Xuecheng (Ocean University of China):***

   In the early 2000s, he optimized membrane separation and low-temperature concentration processes for phycocyanin, resolving pain points of high-temperature

activity loss, insufficient purity and low yield in traditional workflows, and promoted the upgrade of domestic products from crude extracts to standardized high-purity materials.

9. ***Professor Duan Shunshan (Jinan University):***

   He has long focused on green extraction, activity preservation and circular production technologies for phycocyanin, led the compilation of national industrial testing standards and production specifications for phycocyanin in China, and guided the industry toward green and standardized development.

10. ***Domestic Expert Team for Natural Product Extraction:***

    Since 2010, the team has concentrated on green processes including enzyme-assisted extraction, microcapsule embedding and continuous refining, tackling industrial challenges such as light-induced deactivation and poor stability of phycocyanin, and markedly improving activity retention rate and shelf life of finished products.

(II) Core Research Institutions & University Teams

1. ***Department of Biochemistry, University of California, Berkeley, USA:***

   Pioneered foundational research on phycocyanin molecular structure and spectral characteristics, built laboratory-scale purification technical systems, and laid the global theoretical research foundation.

2. ***National Food Research Institute, Japan:***

   In the 1970s–1980s, it took the lead in researching food applications of phycocyanin, developed formulations for colorants and nutritional fortifiers, and established Japan as an early leader in commercial application.

3. ***Algae Research Team, Institute of Hydrobiology, Chinese Academy of Sciences:***

   Beginning in the 1980s, the team carried out selective breeding of native Spirulina strains adapted to domestic cultivation environments and optimized localized phycocyanin extraction workflows.

4. ***College of Food Science and Engineering, Ocean University of China:***

   It conducts in-depth research on green extraction, activity protection and stability enhancement technologies for phycocyanin, participates in drafting national industrial standards, and advances green and standardized industrial development.

5. ***Joint Research Centre (JRC), European Union:***

After 2010, it spearheaded food safety assessments of phycocyanin, facilitated its inclusion in the EU Colouring Foods catalogue exempt from E-number labeling, and spearheaded the clean label trend.

Part II: Research & Development History of Phycocyanin

(I) Discovery of Components & Fundamental Theoretical Research Phase (Early 20th Century – 1960s)

Fundamental global algae research flourished in the early 20th century. In 1917, French scholars isolated water-soluble blue protein from cyanobacteria for the first time, formally naming it phycocyanin, preliminarily analyzing its protein structure and spectral traits, and launching humanity's scientific understanding of the substance.

From then until the 1950s, academic research centered on the species distribution, component structure and basic physicochemical properties of phycocyanin. Researchers confirmed that phycocyanin exclusively exists in a small number of algae including cyanobacteria and red algae as a unique natural photoactive protein, while verifying its fundamental non-toxic and safe attributes.

In the 1960s, alongside preliminary advances in natural product extraction technologies, US research teams launched lab-scale trials using simple workflows of pure water extraction and low-speed centrifugation to isolate mixed phycocyanin fractions, successfully proving the technical feasibility of extraction and enrichment.

This phase was dominated by theoretical studies, qualitative component analysis and laboratory exploration, lacking mature extraction workflows and industrial production reserves; no commercialized product concepts existed, and research value was confined purely to academic purposes.

(II) Crude Extraction Process Exploration & Laboratory Scale-Up Phase (1970s)

Breakthroughs and commercialization of large-scale Spirulina cultivation technology in the 1970s delivered stable raw material supply for phycocyanin industrialization, shifting research priorities from basic theory to practical extraction process development.

Research teams across Europe, the US and Japan compared multiple technical routes including water extraction, low-temperature maceration and simple cell wall disruption, overcoming foundational technical hurdles in raw material pretreatment, algal cell lysis and crude concentrate concentration. Low-temperature pure water extraction was confirmed as the core process to effectively avoid high-temperature deactivation of phycocyanin, a longstanding industrial pain point.

Concurrent academic safety assessments validated the absence of acute toxicity and sensitization in crude extracts, highlighting superior activity and purity compared to raw

Spirulina powder. During this phase, stable lab preparation and small-batch pilot production of crude phycocyanin extracts were realized. The mixed crude products featured low purity, abundant impurities and poor stability, only deployed for scientific trials and internal formulation testing without entry into commercial circulation channels.

(III) Process Finalization & Functional Verification Phase (1980s)

In the 1980s, Japan systematically improved phycocyanin extraction workflows by optimizing fractional extraction and centrifugal impurity removal processes, enabling pilot-scale mass production of crude phycocyanin extracts and launching standardized primary product categories for the first time.

Meanwhile, academia systematically investigated the functional mechanisms of phycocyanin, quantifying core physiological activities such as antioxidant, immunomodulatory and anti-inflammatory effects. Its dual value as natural colorant and bioactive ingredient was clearly defined, identifying food and health products as its two primary application sectors.

Leading overseas enterprises integrated phycocyanin into commercial supply chains, deploying it as a natural blue pigment and functional raw material in premium dietary supplements and functional food production. China launched parallel technical tracking and literature research, replicating laboratory processes and optimizing parameters to enter a technical reserve stage with no industrialization initiatives; the domestic market fully relied on imported technologies and products.

(IV) Refining Technology Breakthrough & Domestic Technology Introduction Phase (1990s)

Rapid iteration of global separation and purification technologies in the 1990s saw membrane separation, precision centrifugation and preliminary chromatography widely adopted in phycocyanin manufacturing. These technologies efficiently removed polysaccharides, heteroproteins and pigment impurities, drastically elevating product purity, stability and color uniformity, driving the industry’s upgrade from crude extracts to standardized refined products.

Comprehensive toxicological evaluations and safety certifications for phycocyanin were completed across multiple European and American nations, while JECFA issued universal industrial specifications that unlocked cross-border global trade.

Domestic research institutes and leading microalgae enterprises formally introduced mature overseas extraction and refining technologies, adapting workflows to the characteristics of local Spirulina raw materials and tackling targeted technical challenges of high solvent consumption, severe active ingredient loss and inferior product stability. In the mid-to-late 1990s, China commissioned its first batch of pilot production lines for phycocyanin, realizing localized small-batch mass production and breaking the exclusive supply monopoly of overseas manufacturers. Fundamental testing methodologies were simultaneously established to preliminarily control product activity and

safety indicators.

(V) Domestic Mass Production & Process Iteration Phase (Early 2000s – 2009)

Leveraging large-scale cultivation capacity in China's two core Spirulina producing regions of Yunnan and Inner Mongolia, the phycocyanin industry expanded rapidly with multiple standardized mass production lines commissioned nationwide. Full-scale production of food-grade and health-grade crude and refined phycocyanin was achieved, completely substituting imports and establishing China as the world's core raw material supply hub.

The industry continuously advanced green process iteration, widely deploying low-temperature extraction, ultrasonic-assisted cell lysis and water recycling technologies to drastically reduce thermal deactivation of heat-sensitive phycocyanin and significantly boost product yield and activity retention rates. Enterprises segmented product specifications according to downstream demand, distinguishing general food-grade, health-grade and feed-grade variants while establishing internal corporate standards and local production codes.

Domestic products in this phase focused on mid-to-low-end standardized bulk materials, while high-purity monomer phycocyanin remained dominated by overseas manufacturers. Chinese products were exported in volume to Southeast Asia, Europe and North America, steadily expanding global market share.

(VI) High-End Refinement, Product Segmentation & Technology Leadership Phase (2010 – Present)

Since 2010, the global consumer wave of clean labels and natural wellness has forced the phycocyanin industry to upgrade toward high-end, refined and standardized manufacturing. Domestic enterprises, in collaboration with universities and research institutions, overcame core key technologies including macroporous resin separation, column chromatographic refining, enzymatic purification and activity stabilization. High-value-added products such as high-purity C-phycocyanin, allophycocyanin monomers and pharmaceutical-grade ultra-pure phycocyanin have entered mass production, attaining world-class core technology standards and breaking overseas monopolies on high-end technologies.

Green low-carbon and intelligent manufacturing have become mainstream industrial practices, phasing out traditional high-energy, high-loss workflows. Low-temperature continuous extraction, closed-loop water circulation and energy-efficient refining processes have achieved full popularization, drastically lifting industrial environmental performance and production efficiency. Product portfolios are highly segmented, with customized specialized grades developed for distinct scenarios including conventional food, premium health supplements, cosmetics & personal care, food for special medical purposes, pet food and biomedicine.

Parallel to the rollout of national standards and continuous improvement of industrial codes, standardization levels across the phycocyanin sector have risen substantially. Currently, China ranks as the world's largest producer and exporter of phycocyanin, covering the full spectrum of mid-to-low and mid-to-high-end products. Sustained breakthroughs in high-purity monomers and customized functional materials have forged a global industrial landscape of differentiated competition and coordinated development alongside overseas market leaders.

Part III: Commercialization Development History of Phycocyanin

(I) Theoretical Research & Technology Vacuum Phase (Early 20th Century – 1960s)

No commercial phycocyanin products circulated during this period, with the global industry confined to purely academic research. Academia only completed component discovery, structural analysis and basic physicochemical characterization of phycocyanin, lacking mature extraction workflows and industrial manufacturing capacity. Market awareness of phycocyanin was entirely absent, with zero commercial application scenarios and market volume. All research outputs exclusively served fundamental science, carrying no commodity attributes or industrialization value.

(II) Birth of Crude Extracts & Niche Commercialization Start Phase (1970s)

In the 1970s, Mexico launched the first generation of mixed crude phycocyanin extracts based on the world's inaugural large-scale Spirulina cultivation base, marking phycocyanin's formal entry into commercial markets. Products from this era featured low purity, mixed components and poor stability, with vague functional and application positioning. They were only used as auxiliary synergistic raw materials paired with Spirulina powder, added in small dosages to local basic nutritional supplements.

Application scenarios remained limited and market scale minimal; products circulated only in niche regional markets across the Americas without forming a global trade framework. Industrial commercialization remained in embryonic exploratory stages with extremely low market recognition and penetration rates.

(III) Rise of Asia & Preliminary Product Diversification Phase (1980s)

In the 1980s, Japan industrialized targeted phycocyanin extraction technologies and pioneered standardized food-grade and health-grade phycocyanin products. It fully unlocked dual commercial value as natural blue colorant and bioactive ingredient, deploying materials in end products including health capsules, oral liquids and premium snack foods. Successful exports to Southeast Asia, Europe and North America displaced the Americas to establish Japan as the world's core production and trade hub for

phycocyanin.

Global trade rules for phycocyanin took initial shape, with products gradually securing food ingredient approval qualifications across multiple nations. China's domestic market remained fully reliant on imports, with no localized commercial layout launched; only a small number of research institutes conducted technical investigations and laboratory trials without market-ready products.

(IV) Domestic Industrialization Launch & Import Substitution Phase (1990s)

In the 1990s, leading domestic microalgae enterprises broke technical barriers and commissioned localized mass production lines for phycocyanin, launching domestic crude extracts commercially and initiating import substitution in the Chinese market. Early domestic products leveraged cost-performance advantages to target conventional food coloration and basic health supplement markets, filling gaps in local supply, though high-purity premium materials continued to rely on imports from Japan and the US.

The domestic consumer market underwent gradual cultivation, expanding phycocyanin applications from exclusive health product use to natural coloration and nutritional fortification in general foods. Three core global production regions emerged: the Americas, Japan and China, formalizing the basic commercial framework of phycocyanin and transforming the material from a niche research reagent to a mainstream commercial functional raw material.

(V) Production Capacity Leadership & Restructured Global Supply Landscape Phase (Early 2000s – 2009)

Driven by explosive growth in domestic Spirulina cultivation output, the phycocyanin industry expanded rapidly, with China's production capacity ranking first worldwide to become the central global supply hub. Clear, fixed divisions of labor formed across the global industrial chain: overseas market leaders focused on ultra-high-purity monomers, pharmaceutical-grade raw materials, customized premium materials and end consumer brand layout; Chinese enterprises specialized in standardized conventional food-grade and health-grade materials covering mainstream mid-to-low and mid-tier global markets.

Domestic phycocyanin achieved large-volume global exports leveraging advantages in production capacity, cost and integrated supply chains, deployed across food, health supplements, premium feed and other sectors, while full industrial chain business models matured comprehensively. The industry permanently shed its niche raw material positioning to become a core product category within the global natural pigment and functional raw material track, cementing a mature global pattern of tiered competition and coordinated supply between Chinese and foreign manufacturers.

(VI) In-Depth Standardization, High-End Breakthrough & Full-Scenario Penetration Phase (2010 – Present)

After 2010, the industry abandoned extensive development models, shifting market competition from singular price rivalry to comprehensive quality competition encompassing purity, bioactivity, stability, regulatory compliance and customized technical services. Domestic enterprises sustained breakthroughs in high-end refining technologies, realizing localized mass production of high-purity monomer phycocyanin and pharmaceutical-grade variants to successfully penetrate global premium raw material markets and dismantle long-standing overseas monopolies.

Application scenarios achieved comprehensive cross-industry penetration: building on traditional food coloration and health functional raw material uses, emerging sectors including cosmetics & personal care, food for special medical purposes, pet functional food, biomedical materials and premium aquafeed witnessed full-scale expansion. Business models evolved into an integrated comprehensive service framework combining standardized raw material supply, customized product R&D and formulation technical empowerment.

The current global industrial landscape is stable and mature: China dominates supply of full-spectrum conventional materials and mid-to-high-end customized products, capturing the vast majority of global market share; overseas enterprises specialize in ultra-pure monomers, cutting-edge compound formulations and premium end-consumer markets. The entire industry has entered a mature stage of standardized, refined and internationally coordinated development. Following the improvement of domestic regulatory frameworks post-2018, the phycocyanin industry entered an accelerated growth phase: China’s annual output exceeded 350 metric tons in 2022 and reached 412 metric tons in 2023, maintaining sustained rapid growth momentum.

Part IV: Construction History of Industrial Standard Systems

(I) Initial Establishment of International Standards (1970s – Late 1990s)

During the early industrialization of phycocyanin, no unified global industrial standards existed. Enterprises worldwide followed internal proprietary indicators, leading to inconsistent specifications for product purity, active content, color parameters, solvent residues, microbial counts and heavy metal limits. Severe cross-border trade barriers emerged alongside uneven product quality across the market.

In the 1970s–1980s, Japan and the US released regional guiding specifications aligned with domestic food regulations, preliminarily defining baseline safety indicators for food-grade phycocyanin and standardizing production and application within regional borders. At the end of the 1990s, JECFA issued universal global standards for phycocyanin, for the first time clarifying product definitions, category classifications, reference values for active components, testing methodologies and pollutant/residue

limits, establishing the world's first unified trade code of conduct. The European Union, US FDA and Japan's Ministry of Health, Labour and Welfare subsequently adopted and rolled out supporting regional compliance frameworks, forming a foundational global interoperable standard architecture for phycocyanin.

(II) Gradual Improvement of Domestic Standard System (Early 2000s – 2019)

During China's early phycocyanin industrialization, the absence of dedicated national and industrial standards created regulatory loopholes that enabled flooding of inferior crude extracts, hindering high-end industrial advancement. Starting in the 2000s, domestic regulatory authorities collaborated with research institutes, leading manufacturers and downstream application enterprises to launch systematic standard compilation work.

In 2014, *National Food Safety Standard Standard for Uses of Food Additives (GB 2760-2014)* added phycocyanin to the approved list of legal food additives, explicitly defining its permitted scope of food coloration applications. The industry sequentially released specialized specifications tailored to food, health food and feed sectors, covering the full workflow of raw material cultivation, production processes, activity indicators, safety limits, testing protocols, storage and transportation. Multiple safety thresholds exceed international universal standards, effectively regulating market order and driving industrial transformation from extensive to standardized manufacturing.

(III) Standard Iteration & Upgrading with Enhanced International Discourse Power (2020 – Present)

In 2021, China formally promulgated and implemented *National Food Safety Standard Food Additive Phycocyanin*, filling the gap of exclusive national standards for phycocyanin and unifying nationwide specifications for product production, testing and application. This milestone marked the maturation of China's domestic industrial standardization system.

Subsequent sustained standard iteration and tightening of safety benchmarks have further lowered permissible limits for heavy metals, microorganisms and solvent residues, optimized modern precision testing techniques, introduced new industrial requirements for green manufacturing and intelligent process control, and supplemented customized specifications for segmented product categories.

Supported by China's complete full industrial chain, massive production capacity and rigorous standard framework, Chinese phycocyanin specifications have evolved into vital global reference benchmarks. Domestic research institutions and leading manufacturers deeply participate in international standard forums and revision activities, continuously elevating China's discourse power in drafting global phycocyanin industrial rules and exporting technical norms, advancing the international recognition of Chinese industrial standards.

Part V: Expansion of End-Use Applications & Deepening Functional Research

(I) Initial Application Embryonic Phase (1970s – 1990s)

In the early commercialization stage of phycocyanin, products were predominantly mixed crude extracts constrained by limited technical maturity, poor activity stability and low purity, severely restricting applicable scenarios. The industry solely leveraged its basic nutritional attributes and natural blue coloring capacity as fundamental nutritional fortifiers and simple colorants, primarily deployed in dietary supplements, basic health products and niche snack foods. Functional positioning remained singular with narrow application coverage, minimal deep-processed derivative products and extremely low market penetration.

(II) Clarified Functional Mechanisms & Popularization of Traditional Application Scenarios (Early 2000s – 2009)

Continuous deepening of research into phycocyanin's functional mechanisms enabled quantitative verification of its targeted physiological effects including antioxidant, immunomodulatory, anti-inflammatory and cellular repair activities. The industry completed a dual positioning upgrade, shifting perception from a "composite nutritional raw material" to a "targeted functional raw material + natural colorant".

Application scenarios rapidly gained market traction:

- Food sector: Deployed as a clean-label natural blue pigment to replace synthetic artificial colorants in beverages, confectionery and baked goods;
- Health supplement sector: Marketed for antioxidant, anti-fatigue and immunomodulatory benefits across tablets, capsules, oral liquids and other finished dosage forms;
- Agriculture & livestock sector: Utilized as a premium nutritional additive in aquafeed and livestock feed to improve farmed product quality.

Phycocyanin emerged as a conventional functional ingredient across multiple industries, driving rapid expansion of overall market volume.

(III) Precision Customization & Diversified Cross-Industry Application Phase (2010 – Present)

Aligning with global consumption upgrading trends centered on natural wellness, clean labels and efficacy-driven skincare, the phycocyanin industry entered an era of refined, customized and cross-sectoral development. Leveraging a product matrix differentiated by purity, bioactivity and stability, precise tailored applications have been realized across all end sectors:

1. ***General Wellness & Food for Special Medical Purposes:***

   High-purity phycocyanin and allophycocyanin, valued for exceptional bioactivity and safety, are incorporated into premium health supplements, sports nutrition formulations and foods for special medical purposes, targeting immunoregulation, antioxidant and bodily repair functions.

2. ***General Food Sector:***

   As the sole mass-producible natural blue pigment, standardized food-grade phycocyanin is widely applied in beverages, dairy, bakery, condiments and frozen foods, comprehensively substituting synthetic blue colorants to align with clean-label consumer demand.

3. ***Cosmetics & Personal Care Sector:***

   Supported by antioxidant, soothing anti-inflammatory, skin repair and anti-photoaging properties, phycocyanin is extensively formulated into serums, facial masks, lotions and cleansing products, serving as a core natural active ingredient to meet demands of clean beauty markets.

4. ***Agriculture, Livestock & Pet Industry:***

   Functional phycocyanin additives are integrated into premium aquafeed, pet staple diets and functional pet treats to boost immunity in livestock and aquatic species, optimize pet nutritional profiles and unlock incremental industrial market opportunities.

5. ***Biomedicine & Cutting-Edge Frontiers:***

   Ultra-pure pharmaceutical-grade phycocyanin has entered pharmacological research and clinical pilot trials, demonstrating tremendous potential in developing anti-inflammatory, anti-tumor and antioxidant pharmaceuticals. Exploratory cutting-edge applications including biological probes and biomaterials are also under continuous development.

Furthermore, raw material compounding technologies have achieved full popularization. Synergistic blending of phycocyanin with probiotics, natural plant extracts, vitamins and other ingredients amplifies overall product functional value. Enterprises establish differentiated competitive advantages in high-end cross-industry tracks through customized material supply and formulation technical service packages.

Part VI: Future Industry Outlook

After a century of theoretical accumulation, over four decades of technological iteration and market cultivation, the phycocyanin industry has built a complete high-end industrial ecosystem spanning strain breeding, standardized cultivation, green extraction, precision refining, activity stabilization and full-scenario end-product deployment. Backed by core competitive strengths of natural safety, unique color spectrum, diverse biological functionality and broad formulation compatibility, compounded with global industry dividends including natural raw material substitution, green manufacturing upgrades and rising health-conscious consumption, the industry will sustain advancement centered on six core strategic directions:

1. ***Targeted Breeding of Specialized Strains & Source Quality Improvement***

Focus on selective breeding of dedicated *Arthrospira platensis* strains featuring high phycocyanin content, strong stress resistance and superior stability. Optimize algal biomass composition via biological breeding technologies to elevate active ingredient concentrations and extraction yields at the source, reduce production costs and consolidate foundational raw material supply chains.

2. ***Green & Intelligent Upgrading of Manufacturing Workflows***

Full-scale popularization of low-temperature cell lysis, enzyme-assisted extraction, closed-loop water circulation and solvent recycling low-carbon green processes; advance automated, intelligent and continuous production line retrofits to realize precise real-time control of temperature, duration and impurity levels throughout manufacturing, further cutting energy consumption, minimizing material loss and enhancing product stability alongside batch consistency.

3. ***High-End Product Development & Refined Monomer Iteration***

Prioritize R&D of high-value-added products including ultra-high-purity phycocyanin monomers, allophycocyanin, pharmaceutical-grade intermediates and certified reference standards, overcome high-end technical barriers to fill gaps in premium material supply, and continuously boost product premium pricing power and global high-end market influence.

4. ***Deepened Fundamental Research & Refined Functional Mechanism Framework***

Sustain in-depth investigation into phycocyanin’s molecular action mechanisms, targeted physiological efficacy, human absorption and metabolic pathways, as well as stability regulation mechanisms. Improve pharmacological, toxicological and functional evaluation systems to deliver robust theoretical support for compliant functional claims, emerging application scenarios and novel efficacy developments for premium products.

5. *Sustained Cross-Industry Expansion of Application Scenarios*

While consolidating established markets of food coloration, traditional health supplements and feed additives, deepen penetration into incremental emerging tracks including food for special medical purposes, premium cosmetics, pet wellness, biomedicine and novel biomaterials. Continuously unlock diversified application value of phycocyanin to expand industrial development boundaries.

6. *Global Collaborative Development & International Standard Export*

Leverage China’s integrated full industrial chain, massive production capacity, proprietary technologies and mature standard framework to deepen cross-border industrial cooperation. Promote international export of advanced domestic manufacturing workflows, testing methodologies and industrial specifications, and steadily strengthen China’s rule-making authority and brand influence within the global phycocyanin industry.

In the years ahead, the phycocyanin industry will steadily advance toward high-end, refined, green, standardized and internationalized development. It will consolidate its position as the world’s leading supplier of natural blue raw materials, evolving into a core benchmark category driving global upgrades in natural functional raw materials and clean-label manufacturing industries.