Top Ten Technical Bottlenecks for NeoProtein in 2025

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Contents

Introduction

China is among the world's largest protein consumers, accounting for 28% of global meat intake, yet faces a considerable supply gap in the years ahead. As unprecedented global changes accelerate—accompanied by the intertwined pressures of climate change, demographic shifts, and geopolitical uncertainty—traditional livestock and fishery systems are encountering mounting resource, environmental, and public-health challenges. Securing national protein supply now confronts immense challenges.

Adopting and advancing a holistic food approach is now a strategic imperative for safeguarding national food security. The Party Central Committee has explicitly called for "adopt a broad perspective on agriculture and food, promoting agriculture, forestry, animal husbandry, and fisheries in tandem to build a diversified food supply system", "expand beyond traditional crops and livestock resources to more abundant biological resources", and "seek calories and protein from croplands, grasslands, forests, oceans, plants, animals, and microorganisms".

As a frontier and revolutionary technology, the NeoProtein industry—represented by plant proteins, microbial proteins, cell-cultivated proteins, and algal proteins—has emerged as a strategic high ground in the global competition for science, technology, and industry. Countries like the US, EU countries, Japan, and Singapore have pioneered the integration of NeoProtein into their national strategies, establishing policy frameworks and innovation ecosystems to advance fundamental research, technology transfer, and market cultivation, profoundly reshaping the global protein supply landscape.

For China, developing a diversified, safe, and sustainable protein supply system is essential not only to strengthen food security and public health, but also to reinforce national technological competitiveness and industrial resilience. However, China’s NeoProtein sector still faces major constraints, including limited foundational research, key technical bottlenecks, insufficient interdisciplinary collaboration, fragmented funding mechanisms, and weak linkages between industry, academia, and research institutions. Addressing these gaps requires coordinated, system-wide action.

To accelerate societal collaboration, the NeoProtein Professional Committee of the Chinese Institute of Food Science and Technology, in partnership with multiple research institutions, universities, and enterprises, has consolidated consensus to produce the report "Top Ten Technical Bottlenecks for NeoProtein in 2025". Focusing on critical junctures in global NeoProtein technological innovation, the report identifies ten most representative technical challenges, research priorities, and recommended technical pathways across core areas. These include efficient raw material extraction, structural simulation, optimization of cell and fermentation systems, intelligent manufacturing, and functional protein innovation.

This report aims to: 1) Define priority breakthrough directions for NeoProtein innovation, providing guidance for research agenda setting and decision-making references for industrial policies; 2) Build a collaborative innovation platform uniting industry, universities, and research academia, forming a closed-loop system of "scientific consensus—technical road map—policy guidance"; 3) Drive China's transition from a "follower" to a "leader" in NeoProtein technology.

The coming decade is a pivotal window for the maturation of the NeoProtein technology system and the reshaping of the industrial landscape. We believe, with coordinated efforts across government, research institutions, and industry—by strengthening original scientific breakthroughs and systematic innovation planning—China is well-positioned to seize strategic initiative in the global race for NeoProtein technologies. Doing so will enable the establishment of a forward-looking system for food safety and sustainable development, contributing Chinese wisdom to human health, ecological civilization, and global food security.

1. Development Opportunities for NeoProtein

1.1. Definition of NeoProtein

NeoProtein broadly refers to all protein resources obtained without relying on traditional livestock farming or fisheries methods, encompassing emerging protein industries such as animal cell-cultivated proteins, plant proteins, microbial proteins, algal proteins, and insect proteins. By leveraging NeoProtein production technologies and robust food processing systems to stably and efficiently produce NeoProtein foods—transitioning from traditional farming and aquaculture models to factory-based manufacturing—we can significantly address challenges in conventional animal protein production. This approach is increasingly becoming a vital pathway for expanding access to edible protein for China's population and humanity worldwide.

1.2. Significance of NeoProtein

(1) Revolutionizing food manufacturing models to achieve high-quality protein supply

Traditional livestock and aquaculture systems face growing constraints related to health, nutrition, and sustainability. In response, future food technologies—driven by the convergence of food technology, biotechnology, and information technology—are reshaping protein production by moving it from fields to factories. Take cell-cultivated meat as an example: grounded in stem cell biology, supported by digital processes, and guided by meat-like structure and flavor, it stands as a quintessential example of the convergence of food technology (FT), biotechnology (BT), and information technology (IT)—the "3T integration". Meanwhile, plant-based proteins, through structural design and recombinant technologies, effectively supplement animal protein while enhancing resource efficiency.This shift supports the supply of high-quality protein, strengthens food security, and provides a crucial technological route toward carbon peak and carbon neutrality goals.

(2) Enhancing Human Health and Ecological Health of the Planet

Traditional animal protein production imposes significant ecological and health burdens: Livestock farming contributes approximately 12% of global greenhouse gas emissions and drives about 30% of terrestrial biodiversity loss; In the EU, two-thirds of agricultural land is used for livestock, intensifying ecological pressures. Diet-related diseases cause 11 million deaths globally each year (including 3 million in China), with excessive animal protein consumption being a primary factor. In contrast, NeoProtein offer significant advantages in resource efficiency and low-carbon footprint: Replacing just 20% of global beef consumption with fungal protein could reduce deforestation and related carbon emissions by 56%; plant-based protein can cut methane emissions by 85%–99%; cell-cultivated chicken and beef could respectively reduce carbon emissions by 17% and conserve 78% of freshwater. Nutritionally, yeast protein boasts over 70% protein content with 96% digestibility; microalgae protein contains 60%–70% essential amino acids. Both surpass traditional protein sources while delivering dual benefits of ecological conservation and health promotion.

(3) Enhancing Protein Production Efficiency to Meet Human's Protein Challenges

With the global population projected to reach 9.8 billion by 2050, meat demand will surge to 1.5 times current levels—a growth traditional farming models cannot sustain. Existing animal protein production is inefficient: pork, for instance, has an energy conversion rate of just 9%. In contrast, NeoProtein sources can efficiently synthesize protein directly from primary raw materials: per 1,000 kilograms of yeast, soybeans, and dairy cows, 2,000 kilograms, 10 kilograms, and 1 kilogram of protein can be produced within 24 hours, respectively. Given the rising pressure on global protein supply, NeoProtein sources—ranging from plants and insects to marine organisms—offer a high-efficiency, sustainable pathway to meeting future demand.

1.3. Market Value and Comprehensive Benefits of NeoProtein

According to a report by Boston Consulting Group (BCG) and Blue Horizon, the NeoProtein market is projected to reach 97 million tons by 2035, accounting for at least 11% of the global protein market (potentially reaching 22% with accelerated technological development), with an estimated market value of $290 billion. Microbial fermentation protein is expected to emerge as the primary contributor. This growth is driven both by investment—global funding surged from $1 billion to $5 billion between 2019 and 2021—and policy support, such as China's 14th Five-Year Plan explicitly encouraging R&D into "artificial protein." The benefits of NeoProtein are diverse and significant: environmentally, the adoption of plant-based meat and eggs alone could reduce over 1 gigaton of carbon dioxide emissions and conserve 39 billion cubic meters of water by 2035; economically, some plant protein cost only one-third of animal protein to produce, with shorter, more localized supply chains; health-wise, microbial fermentation protein offer more balanced nutrition and improved protein absorption, contributing to enhanced public health.

2. Current Landscape of NeoProtein Development in China

2.1. Market Status of Plant-Based Protein (Plant-Based Meat and Semi-Finished Products)

Driven by health-conscious diets and environmental awareness, China's plant-based protein (plant-based meat and semi-finished products) market is rapidly expanding. By 2024, its sales accounted for approximately 24.5% of the global market, and it is projected to grow at a compound annual growth rate (CAGR) of 9.2% to reach $3.5 billion by 2028. Current products primarily utilize soybeans, peas, and wheat as raw materials, gradually expanding to include legumes like mung beans and chickpeas. These are processed into minced meat, meat chunks, and various pre-formed products to meet diverse consumer demands. The market features numerous participants but a fragmented competitive landscape, with sales primarily through dual channels: B2B (e.g., high-end catering) and B2C (e.g., e-commerce and import supermarkets). Core selling points center on health attributes (high protein, low cholesterol, zero trans fats, etc.) and environmental sustainability. However, the industry still faces challenges such as limited offline channels and high production costs leading to elevated prices. Future market expansion is expected through technological advancements and cost optimization.

2.2. Current Development of Microbial Protein

Driven by both policy support and technological innovation, China's microbial protein industry is experiencing vigorous growth, achieving breakthroughs in key areas such as strain selection, genetic modification, and efficient production. The application of advanced technologies like microfluidics and scarless genome editing has significantly enhanced industrial efficiency and feasibility. Several companies have achieved large-scale production: Angel Yeast operates 12 global production lines for brewer's yeast protein, which has received national approval as a new food ingredient. Fusarium venetum protein has gained FDA certification and get China's National Health Commission approval for new food ingredients. Microbial protein’s alignment with low-carbon agriculture and national sustainability objectives creates strong long-term growth momentum. Additionally driven by both policy and market forces, it will have more products enter the market to meet diverse demands for health, environmental protection, and sustainability.

2.3. Current Status of Cell-Cultivated Protein (Meat) Development

China's cell-cultivated protein (meat) industry has achieved a major breakthrough from laboratory research to scaled-up production through technological innovation and process optimization. By establishing a high-throughput screening platform for functional factors, three key signaling pathways regulating myolipid differentiation and protein synthesis were successfully identified. This led to the development of technologies for directed muscle fiber differentiation and quality enhancement, increasing the efficiency of in vitro muscle fiber generation by 1.8–3.6 times. In production systems, advanced processes such as batch feeding and wave-type reactor perfusion have been established. A bioreactor production line ranging from 5L to 200L has been constructed, enabling stable pilot-scale production of cell-cultivated pork and mass production of chicken at the hundred-liter scale. Diverse products, including marbled pork chops, have been successfully developed. Key cost bottlenecks have been effectively controlled through the independent development of serum-free culture media and specialized bioreactor systems. As the production chain matures and technology continues to evolve, China's cell-cultivated meat industry is poised to play a significant role in advancing global food sustainability and safety.

3. Key Challenges in the NeoProtein Sector

Currently, the development of NeoProtein faces challenges in achieving high quality protein, rich nutrition, realistic texture, authentic flavor, and natural color. The primary task is to ensure protein quality by optimizing digestibility and amino acid composition to enhance bioavailability. Beyond basic protein content, developing a comprehensive micronutrient fortification system is essential. Achieving realistic texture requires precisely mimicking muscle fiber structure and chewiness through techniques like high-moisture extrusion and enzymatic cross-linking, while also addressing juice retention and shape stability during cooking. Flavor enhancement necessitates integrated approaches including off-flavor removal, Maillard reaction regulation, and biosynthetic flavor compounds (e.g., hemoglobin) to replicate characteristic animal meat flavors while ensuring long-term stability. Color simulation relies on developing plant-based and bioengineered pigments, coupled with establishing stable pigment-matrix complexes to reproduce color changes during cooking.

3.1. Challenges in Plant-Based Protein

Plant-based protein face multiple technical challenges, including fiber structure regulation, flavor and texture, and ingredient systems. Dry-extruded products exhibit loose fiber structures, while wet-extruded ones tend to form overly dense networks that impede flavor penetration. Existing binding systems struggle to achieve multi-layered structural integration, causing products to collapse under cooking shear forces. Flavor-wise, improper moisture distribution control leads to dry, astringent textures and lacks the three-dimensional network characteristic of animal fats. Ingredient systems suffer fundamental shortcomings, such as the absence of efficient cross-linking enzymes and thermoplastic-condensing protein/polysaccharide systems, limiting dynamic textural responsiveness. Biotechnology serves as the core solution to these challenges. Examples include: utilizing transglutaminase to enhance fiber strength; employing specific enzymatic hydrolysis to eliminate off-flavors and reduce allergenicity; applying synthetic biology to reconstruct hemoglobin synthesis pathways for improved color and flavor; and constructing protein-fat composite gels to mimic intramuscular fat structures.

3.2. Challenges in Microbial protein

Microbial protein can be categorized into biomass protein and functional protein. Challenges for biomass protein (e.g., fungal protein, yeast protein) include developing low-cost substrates (e.g., non-grain carbon sources), optimizing efficient and low-energy continuous fermentation processes, and ensuring final protein products possess desirable functional properties such as solubility and thermal stability. Fungal protein exhibit excellent structural properties but complex fermentation control, while yeast protein offer acceptable flavor but poor fibrillation.

Targeted strain selection and process regulation are required. Microbial functional protein rely on synthetic biology to precisely ferment specific functional components like lactoferrin and hemoglobin. Technical bottlenecks include inefficient protein synthesis and secretion systems; difficulty replicating complex post-translational modifications (e.g., human glycosylation patterns); exogenous protein are susceptible to degradation by host proteases; and for multi-subunit complexes like hemoglobin, challenges include insufficient endogenous cofactor supply and imbalanced subunit ratios, complicating folding and assembly.

3.3. Challenges in Cell-Cultivated Protein (Meat)

Animal cell-cultivated protein (meat) represent a technological "high ground", with challenges spanning the entire production chain. At the seed cell level, developing pluripotent stem cell lines capable of stable proliferation and differentiation is essential. Co-culturing adipocytes to mimic the complex tissue architecture of real meat is crucial. Developing edible scaffolds or microcarriers that simulate the extracellular matrix is key to achieving structural realism. Cost control hinges on serum-free medium development, requiring low-cost substitutes for serum's numerous growth factors and hormones. Bioreactor design must enable high-density 3D cell growth and vascularized networks while maintaining sterility and controllability to prevent internal cell necrosis. Currently, cultivating thick muscle tissue with complex structures remains challenging.

3.4. Other NeoProtein

Beyond plant-based protein, microbial protein, and animal cell-cultivated protein, other NeoProtein sources like algal protein and insect protein are gaining attention for their sustainable production methods. Taking algal protein as an example, it boasts high protein content but faces multiple constraints: selecting superior industrial strains, achieving large-scale low-cost cultivation efficiency, developing efficient cell-wall disruption techniques for tough cell walls, multi-component separation and purification, and ensuring product flavor and safety (e.g., deodorization and desensitization).

4. Top Ten Technical Bottlenecks for NeoProtein in 2025

Based on current challenges in the NeoProtein field and emerging trends for 2025, the NeoProtein Professional Committee of the Chinese Institute of Food Science and Technology collected technical issue proposals from over 40 participant attendances and held three online exchange seminars. This process identified the top ten technical bottlenecks for NeoProtein in 2025:

(1) Green and High-Efficiency Extraction Technology for Low-Denatured Plant protein

Plant-based proteins constitute a vital component of NeoProtein. Currently, the alkali-soluble acid-precipitation wet separation method is the most common approach for extracting pea protein. However, the wet extraction process involves drastic changes in pH and temperature, which can disrupt the natural structure of plant protein, leading to irreversible aggregation due to denaturation. Consequently, existing extraction technologies suffer from high energy consumption, significant pollution, and protein denaturation issues, severely limiting the functional properties of plant protein and their application in plant-based foods.

To address these challenges, the development of low-denaturation, green, and efficient protein extraction pathways should be prioritized. A novel mild extraction process centered on dry separation and aqueous phase separation can be systematically developed. This approach fully leverages the physical differences between plant protein and non-protein components in terms of particle size, density, and surface properties. By constructing a spiral airflow field, protein can be efficiently and precisely separated based on differential sedimentation rates. Building upon this foundation, further integration with aqueous phase extraction techniques enables gentle enrichment and purification of protein components. This environmentally friendly approach maximizes the preservation of protein integrity, natural conformation, and functional properties, effectively avoiding denaturation, aggregation, and functional loss caused by traditional extraction methods.

Systematic advancement and application of such green extraction technologies will significantly enhance the quality and industrial benefits of plant-based protein raw materials: On one hand, it substantially improves functional properties such as solubility, emulsification, and gelling characteristics, providing premium raw material support for high-quality plant-based meat and dairy alternatives. On the other hand, it promotes low-carbon transformation in production processes by reducing energy consumption and pollution, thereby strengthening industrial sustainability and economic viability.

(2) Construction of Meat-like Multi-dimensional Structure and Enhancement of Juiciness Simulation in NeoProtein

China's NeoProtein meat-like products still face significant shortcomings in realism, with core technical bottlenecks including: functional limitations of single-source plant protein that cannot simultaneously achieve good gelation, water-holding, and oil-holding properties. This results in inferior texture and flavor compared to traditional meat, particularly a noticeable lack of juiciness, severely hindering consumer acceptance and industry adoption.

To address these issues, systematic technological breakthroughs can be pursued through three pathways: First, scale-up production of functional NeoProtein by combining biotechnology with physical field treatment to optimize protein structure, reduce denaturation and aggregation, and enhance functional properties. Second, develop synergistic fusion technology for heterogeneous NeoProtein, designing specialized mixing equipment to achieve protein network integration at high solids content, thereby constructing high-strength, high water/oil-holding three-dimensional structures. Third, implement structural engineering of natural plant oils. Utilize bioprocessing pretreatment and physical field reorganization to construct realistic fat components that mimic meat's juiciness.

Systematically advancing these technological developments will enable dual breakthroughs in chewiness and juiciness for NeoProtein meat alternatives, significantly enhancing product realism and overall flavor experience. This will propel the NeoProtein industry toward higher quality and broader consumer acceptance, strengthening its role in supporting national food strategy.

(3) Development of Myogenic Cell Lines with Stable Long-term Passaging Capacity for Cultivated Meat Applications

Cell-cultivated meat aims to efficiently biosynthesize high-quality animal protein and address challenges in traditional livestock farming. As the key chassis cells for synthesizing muscle protein, the quality of myogenic cell line construction determines production efficiency and product quality. Therefore, the creation of immortalized myogenic cells is central to industrial breakthroughs. Currently, establishing immortalized myogenic cell lines faces three major bottlenecks: First, primary myogenic cells are constrained by the Hayflick limit, making it difficult to achieve immortal proliferation while maintaining core cellular functions. Second, balancing proliferation and differentiation capacity—existing cell lines enhance proliferation efficiency but often compromise myogenic differentiation potential. Third, safety and stability concerns persist, as long-term passage may induce genetic mutations, and the absence of unified quality standards compromises food safety and consistent production processes.

To address these bottlenecks, research should focus on three key areas: First, leverage single-cell sequencing and proteomics to identify critical balance points between "key fate decisions in cellular immortalization" and "regulatory mechanisms for maintaining differentiation capacity", thereby clarifying the "key signaling pathways" governing cell growth to provide theoretical foundations for cell line construction. Second, integrate CRISPR-Cas9 gene editing with cell domestication to enhance proliferation capacity and environmental tolerance. Supplement this with epigenetic regulation to optimize the cell cycle while preserving differentiation potential. Additionally, incorporate epigenetic modulation techniques such as histone modifications and DNA methylation regulation to optimize expression of cell cycle-related protein, thereby extending passage numbers while maintaining differentiation capacity. Third, establishing a quality evaluation system defines core metrics like proliferation rate and differentiation efficiency, formulating standardized procedures to support compliant applications.

The creation of immortalized myogenic cells provides stable cellular resources for continuous, standardized production in bioreactors, overcoming the limitations of primary cells to enhance production efficiency and product consistency. Simultaneously, it systematically reduces unit meat production costs by lowering cell acquisition expenses, optimizing cultivation processes, and enabling process scaling, thereby laying a robust technological foundation for the commercialization of cell-cultivated meat.

(4) Establishment of a Scalable Serum-free Culture System for Cultivated meat

As an emerging sustainable food resource, cultivated meat holds immense potential in the future food and NeoProtein sectors. However, during its industrialization process, critical technical bottlenecks persist in culture medium development, severely hindering cost reduction and large-scale application. Current challenges manifest in four key areas: First, cell culture heavily relies on animal-derived components such as fetal bovine serum, which are not only costly and limited in supply but also pose ethical concerns; Second, the complex composition of nutrients in culture media and the significant differences in requirements among various cell types lack systematic optimization models. Third, the signaling molecules and regulatory mechanisms in serum-free culture media remain incompletely elucidated, leading to inefficient cell growth and differentiation. Finally, the utilization efficiency of culture media in large-scale bioreactors is insufficient, failing to meet nutrient supply demands in high-density environments.

Technological breakthroughs can be pursued through the following avenues: First, develop plant-derived, recombinant protein, and small-molecule alternatives to progressively replace animal serum, reducing cultivation costs and enhancing sustainability. Second, integrate multi-omics data with artificial intelligence algorithms to decipher metabolic requirements and signaling pathways across cell types, establishing precise medium design and optimization models. Third, employ synthetic biology and protein engineering to rationally design growth factors, cytokines, and carrier protein, improving cell proliferation and differentiation efficiency. Fourth, integrating bioreactor engineering design with dynamic nutrient regulation technology to enhance medium utilization efficiency for high-density culture requirements.

The development of serum-free culture media for cell-cultivated meat represents a core driver for achieving industrial-scale production and cost control. At the application level, it establishes a stable, controllable, and standardized supply chain by eliminating dependence on animal-derived components like fetal bovine serum, laying the foundation for large-scale, continuous bioreactor production. Regarding cost control, serum-free culture media not only directly eliminate serum expenses—which constitute the bulk of production costs—but also provide a platform for precise nutritional optimization, waste reduction, and long-term process iteration through chemically defined formulations. This systematically lowers unit production costs, laying a solid foundation for the commercialization and market competitiveness of cell-cultivated meat.

(5) Construction of the Highly Efficient Cell Factory for Fermented Microbial Biomass Protein Production

Microbial fermentation-derived biomass protein hold promising prospects as food and feed protein sources. However, China faces significant bottlenecks in high-protein strain selection and enhancement of biomass protein synthesis pathways. Core technical bottlenecks in the microbial fermentation industry include limited protein synthesis efficiency, upper limits on biomass accumulation, and poor coordination in amino acid synthesis.

To address these challenges, systematic technological breakthroughs can be pursued through three major pathways: First, identify and develop novel hosts better suited for food protein production —such as non-traditional yeasts, fungi, or bacteria— and utilize adaptive evolution and metabolic network reconstruction to maximize carbon and energy diversion toward target product synthesis pathways. Second, comprehensively enhance protein synthesis pathways by optimizing amino acid and cellular protein biosynthesis at the transcriptional/translational levels, protein folding and secretion stages, and precursor/energy supply systems. Third, integrating adaptive laboratory evolution with high-throughput screening technologies to establish automated platforms. These platforms will rapidly identify high-protein strains using effective reporting systems (e.g., fluorescent labeling, growth coupling) while automating strain construction, cultivation, and detection processes, thereby accelerating the iterative optimization cycle of cell factories.

Systematically advancing these technological developments will enable efficient biomanufacturing of biomass protein, promote circular economies, catalyze emerging green industries and high-value markets, fulfill sustainability commitments, and provide stable, efficient, and sustainable new sources of protein raw materials.

(6) Intelligent Design of Protein Biomanufacturing Reactors and Process Control for High-Density Fermentation

The intelligent design of protein biomanufacturing reactors and process control directly impacts target protein production efficiency and industrial economic benefits. The core technical bottleneck currently facing the industry lies in achieving highly autonomous, efficient, and stable "scale-up effects" during high-density fermentation of strains in existing bioreactors. There is a current lack of effective sensors capable of real-time, online, and precise monitoring of key biological parameters. Most parameters rely on frequent sampling and analysis, resulting in significant lag. Simultaneously, the metabolic state of the strains themselves changes over time, exhibiting poor universality, making it difficult to accurately describe this complex system with mathematical models (mechanistic or data-driven models).

To address these challenges, systematic technological breakthroughs can be pursued through three primary pathways: First, the design and modularization of novel intelligent reactors. Computational fluid dynamics simulations of flow fields, shear forces, and mass transfer efficiency within reactors of varying scales will drive the transition from batch to continuous fermentation processes, enhancing stability and controllability. Second, developing novel online monitoring and advanced process analytical technologies. This involves creating new online sensors based on spectroscopy (e.g., near-infrared NIR, Raman spectroscopy) and capacitance principles. Machine learning algorithms will be employed to construct correlation models between multidimensional parameters, enabling real-time inference of critical biological parameters. Third, implement AI-driven control by establishing a digital twin system corresponding to physical reactors. Analyze massive process data using machine learning algorithms to enhance long-term control strategies, enabling adaptive and predictive reactor control while optimizing operational parameters.

Systematically advancing these technological developments will enable autonomous, high-density fermentation of microbial strains, significantly boost protein yields, optimize production efficiency and economic benefits, ensure consistent product quality and stable production. It will also drive the industry's transition toward flexible, digital production models, facilitating the manufacture of diverse high-value protein products and enabling rapid response to market demand fluctuations.

(7) Precision Design of Yeast Chassis Cells for Efficient Expression of Functional Proteins

Most functional protein possess outstanding properties and wide applications, forming a crucial component of the NeoProtein industry. However, significant shortcomings currently exist in the precise design of *Pichia pastoris* and *Saccharomyces cerevisiae* chassis cells, the correct folding and secretion of protein, and the global regulation of metabolic pathways. Core technological bottlenecks facing the industry include: insufficient precision and diversity of genetic tools and regulatory elements, with a need for optimized efficient and scar-free gene editing tools; substantial metabolic burden imposed on host cells by exogenous functional protein expression; and research bottlenecks in protein folding, secretion, and degradation processes, where exogenous protein in yeast are prone to misfolding, inclusion body formation, or retention in the endoplasmic reticulum, leading to inefficient secretion.

To address these challenges, systematic technological breakthroughs can be pursued through three primary pathways: First, develop synthetic biology toolkits to establish precise regulatory systems. By advancing component engineering, CRISPR technology upgrades, and metabolic pathway design, we can reduce the metabolic burden on the host organism and achieve precise control over protein expression. Second, integrate machine learning for global optimization of chassis networks, identify metabolic bottlenecks and stress response genes triggered by exogenous protein expression, and rationally design and construct more efficient yeast chassis cells. Third, reconstruct protein synthesis and secretion pathways by re-establishing post-translational modification modules and glycosylation pathways within the yeast chassis to promote proper protein folding.

Systematically advancing these technological developments will facilitate the customization of cellular factories for efficient expression of various specialty industrial enzymes. This will drive the replacement of industrial processes with "enzyme catalysis", fostering greener, more sustainable biomanufacturing pathways. Concurrently, these technologies will propel the development of novel functional protein industries, enabling production for applications in NeoProtein, precision nutrition, biosensing, and other fields. This will establish a new industrial model for customized functional protein.

(8) Integration Technology for Low-carbon Processing of Edible Fungal Protein and Automated Solid State Fermentation

Low-carbon processing and equipment integration for edible fungal protein are critical for upgrading the industry. However, multiple technical challenges persist. Key issues include: uneven temperature and humidity distribution in traditional fermentation processes, large fluctuations in metabolic byproducts, and difficulty achieving real-time precise control of process parameters. In large-scale production, these issues can lead to poor fermentation stability, high energy consumption, and low equipment integration. Moreover, prolonged high-temperature processing often cause protein denaturation and reduced functional activity, severely compromising product quality and nutritional retention.

To address these bottlenecks, technological breakthroughs can be advanced through three approaches: First, establish an intelligent control system for solid-state fermentation that combines in-situ sensing technologies with AI-driven dynamic optimization. Utilizing hyperspectral imaging, the system can monitor mycelial biomass and metabolic markers in real time, enabling dynamic self-adjustment of parameters such as temperature, humidity, aeration, and gas exchange to maintain stable fermentation conditions. Second, systematically optimize fermentation processes by regulating key including substrate formulation, carbon-to-nitrogen ratio, aeration rate, and oxygen gas partial pressure. A multi-parameter online monitoring and feedback control system will enhance production stability and yield. Third, develop low-carbon processing technologies by integrating non-thermal methods (e.g., cold plasma, high-pressure processing) with enzymatic modification to improve protein under mild conditions, as well as a complementary nutritional retention and functional evaluation systems to ensure high quality protein products with minimal thermal damage.

This integrated, systematic solution combining intelligent sensing, AI, and non-thermal processing will significantly accelerate the standardization and green transformation of edible fungal protein production, achieving "three enhancements and three reductions”: enhanced product quality, efficiency, and application value while lowering energy consumption, cost, and environmental impact. Ultimately, these advances will drive the industry toward standardized, large-scale, and low-carbon manufacturing; strengthening China's self-sufficiency in food protein supply, and support the high-quality, sustainable development of the neoprotein industry.

(9) Optimization of Processability and Multi-scenario Application of Yeast Protein

As a highly nutritious and sustainable microbial protein, yeast protein holds immense potential within the neoprotein industry. However, its industrial application faces a critical bottleneck in limited processing adaptability. The natural aggregation of yeast protein results in larger particle sizes, and poor solubility and emulsification properties, limiting its broad application into diverse food systems. Additionally, incomplete understanding of its protein composition and structure, combined with a lack of research on its interactions within complex food matrices, constrains its application across multiple application and development scenarios.

Strategies to address these challenges can be approached from three angles: First, employing physical nano-modification techniques such as high-pressure microjet processing and ball milling to reduce protein particle size. Therefore, enhancing solubility, emulsification capacity, and gelling properties to improve product stability and texture. Second, integrating proteomics and bioinformatics methods to reveal its multilevel structure and post-translational modifications. It will also establish structure-activity relationship models and leverage its unique structural advantages to expand into niche areas like fat mimetics. Third, establish a multidimensional evaluation network encompassing thermal properties, rheological behavior, and digestive performance to systematically assess yeast protein compatibility in gelation, emulsification, and foaming systems, thereby broadening application scenarios.

Achieving these technological breakthroughs will significantly enhance yeast protein solubility and stability, driving its adoption in high-value segments such as protein beverages, plant-based meat, and dairy analogs. A clearer understanding of structure-function relationships will facilitate the development of premium products such as medical nutrition and personalized dietary solutions. Improved processing adaptability will facilitate cross-industry applications, enhance supply chain resilience, improve industrial competitiveness, and advance sustainable protein supply systems.

(10) Protein Enrichment and Quality-enhanced Utilization of Fusarium Venenatum

Mycelial protein derived from *Fusarium venetum* has been internationally recognized as a novel, nutrient-rich, and safe protein source. It was classified as a novel food ingredient by China's National Health Commission in 2025. However, its rigid cell wall composed of chitin-glucan severely hinders protein release and human digestibility. This results in low functional and nutritional utilization rates, posing a common technical bottleneck that constrains the development of high-value-added products.

To address extraction difficulties and low digestibility associated with this structural barrier, green and efficient extraction technologies can be developed through two primary pathways: First, developing a multi-stage extraction process combining high-pressure homogenization with pH shift solubilization. This approach uses mechanical shear force to disrupt cell walls for efficient protein separation, incorporating enzymatic pretreatment can further reduce energy consumption and enhance breakdown. Additionally, electrostatic separation technologies based on differences in dielectric properties between proteins and cell wall components can physically screen components with minimal chemical input. Second, employing CRISPR-based gene editing to selectively knockout or downregulate genes associated with synthesis of key cell wall components—chitin and glucan. Reducing *Fusarium venenatum* cell wall thickness and rigidity, thereby enhancing intracellular protein accessibility and utilization during subsequent extraction and processing.

This systematic breakthrough in efficient cell wall disruption, separation, and extraction technologies will significantly enhance the product quality and industrial competitiveness of *Fusarium venetum* protein. It can effectively improve protein digestibility and bioavailability, enable functional performance comparable to whey protein, and meet the stringent protein quality requirements of high-end markets such as medical nutrition, sports nutrition, and infant formula.

5. Strengthen Policy and Fund Investments to Concentrate Efforts on Tackling the Top Ten Technical Bottlenecks for NeoProtein

The world today is undergoing profound and accelerated changes. Food security, resource constraints, and increasing public aspirations for a higher life quality collectively form the major challenges of our era. Within this context, developing the neoprotein industry is no longer an optional choice but an imperative necessity concerning national security, public health, and global competitiveness. It is also an essential step in implementing a holistic food perspective and building a diversified food supply system.

We must adopt a forward-looking strategic vision to strengthen top-level policy planning, direct science and technology investments towards high-impact areas, and concentrate efforts on tackling the ten core technological bottlenecks in the neoprotein sector. This will foster new models for food protein production and cultivate emerging industrial and societal needs. Ultimately achieving a historic leap from "supplementation" to "substitution", and then to "expansion" and "irreplaceability" within the global food system.

To this end, we propose the following actions:

1. **Develop a national strategy and roadmap for the neoprotein industry, clearly defining the priorities and timeline for technological breakthroughs to guide research, industry, and related stakeholders toward shared objectives.**
2. **Support the establishment of a national collaborative innovation platform for neoprotein, expand fiscal funding support, establish a major national science and technology project dedicated to neoprotein, and integrate it into the national key R&D program;**
3. **Create an innovation-friendly regulatory sandbox system to provide fast-track review and approval channels for new technologies and products while ensuring rigorous safety standards. Strengthen standards and certification systems to regulate market order and enhance consumer confidence;**
4. **Encourage local governments to incorporate the top ten technical bottlenecks for neoprotein into regional industrial planning and science and technology initiatives. Establish industrial guidance funds, build specialized industrial parks, and offer preferential access to land, energy, and data resources to foster globally influential industrial clusters;**

5. **Mobilize industrial capital to invest boldly in R&D and pilot-scale platforms, supporting cross-disciplinary and cross-sectoral collaboration. "Patient capital" should accompany frontier technologies through the critical "valley of death" between laboratory discovery to market commercialization.**
6. **Encourage researchers to overcome disciplinary boundaries and jointly tackle technical bottlenecks, actively promoting deep integration among industry, academia, and research institutions to ensure scientific advances become the driving force for industrial upgrading.**

The window of opportunity is now open—only innovators advance, and only the diligent prevail. With firm strategic commitment, let us unite the collective efforts of government, academia, industry, and finance. By precisely directing policies and funding toward the cutting edge of the ten key bottlenecks in neoprotein, China will not only meet the public's rising demands for a healthier & higher quality diet but also establish itself as a global hub for scientific innovation and industrial development in neoprotein. Through these efforts, China will contribute its knowledge and solutions to the sustainable development of human society. The investments made today will undoubtedly secure a safer, healthier, and greener future for our dining tables—benefiting both and future generations.

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	Zhu Lianming	Lianyungang Bailun Biotechnology Co., Ltd.	Chairman

Appendix 2: Key Technical Breakthroughs and Highly Cited Papers in Last Five Years

[1] Humpenöder, F., Bodirsky, B. L., Weindl, I., Lotze-Campen, H., Linder, T., & Popp, A. (2022). Projected environmental benefits of replacing beef with microbial protein. Nature, 605(7908), 90-96. https://doi.org/10.1038/s41586-022-04629-w

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