Development History of Xylitol Industry

Part 1: A Tribute to the Pioneers

As a natural pentahydroxy sugar alcohol with a long application history, xylitol boasts outstanding properties including pleasant sweet taste, low calorie, anti-caries effect, good metabolic compatibility and adaptability to special diets. After centuries of iterative development, it has formed a complete industrial chain covering substance discovery, mechanism analysis, process exploration, technological innovation, safety verification, regulatory certification and global commercialization. Evolving from a rare laboratory substance in the late 19th century, to an industrially mass-produced product in the mid-to-late 20th century, and further to a globally popular core functional ingredient manufactured via green biological processes in the 21st century, the industrial upgrading of xylitol embodies the painstaking efforts and perseverance of generations of researchers, engineers, standard setters and practitioners across the whole industrial chain worldwide.

Over the century-long industrial development, generations of researchers have devoted themselves to basic research, overcoming process bottlenecks, verifying product efficacy and improving safety systems; front-line engineers have optimized production processes repeatedly to realize large-scale production and domestic technological independence; industrial practitioners have expanded market layout, improved supply chain systems and promoted global popularization. Hereby, we pay the highest tribute to all individuals, research teams, universities, research institutions and upstream and downstream enterprises engaged in basic research, process improvement, safety evaluation, clinical demonstration, standard formulation and industrial promotion of xylitol. In accordance with the principles of industrial competition and enterprise privacy protection, specific enterprise rankings are not presented in this section. We sincerely salute domestic and overseas enterprises that have made outstanding contributions to the development of this industry.

Tribute List

1. Core Scientists and Researchers (Supplement of Authoritative Named Scholars & Full-dimensional Content Optimization)

This chapter is sorted strictly by research timeline, technological breakthrough dimensions and industrial contribution weight. It supplements milestone named scientists in the global xylitol field, integrates personal academic contributions and team research achievements, and presents the full-chain research context of xylitol covering substance discovery, preparation, functional verification, compliance certification and technological catch-up in China. The content avoids repetition and logical confusion, and clearly distinguishes landmark personal contributions from team industrialization achievements.

1.1 Scientists for Xylitol Substance Discovery and Structural Foundation (Late 19th Century: Discipline Initiation Stage)

- ***Emil Fischer (1852—1919, Germany)***:

  Winner of the Nobel Prize in Chemistry, founder of modern carbohydrate chemistry, and the first scientist who discovered and resolved the molecular structure of xylitol. In 1891, together with his student Rudolf Stahel, he first separated and purified xylitol monomers from hydrolyzed products of beech and birch lignocellulose, coined the term "Xylit", accurately analyzed the molecular structure of pentahydroxy sugar alcohol, clarified its chemical properties, basic physical and chemical characteristics and natural existing forms, and initially verified its sweet taste. He also improved the basic theory of polyols, filling the academic gap in the cognition of natural pentahydroxy sugar alcohols. His research laid the original theoretical foundation for all subsequent research and industrialization of xylitol, making him the founder of the xylitol discipline system.

- ***Rudolf Stahel (Germany)***:

  Core research assistant of Emil Fischer and key executor of the first xylitol separation experiment. From 1890 to 1891, he participated in the whole process of raw material component decomposition and separation and purification experiments of birch wood, optimized the initial laboratory extraction method, and obtained high-purity xylitol samples. He assisted Fischer in completing molecular structure determination and academic conclusion, serving as a core contributor to the discovery of xylitol.

- ***M. G. Bertrand (France)***:

  An independent scholar conducting synchronous research who pioneered a new extraction route of xylitol from herbaceous raw materials. In 1891, he independently extracted xylitol syrup from wheat and oat straws, confirming that xylitol widely exists in woody and herbaceous plants. His research broke the limitation of single birch raw material, improved the theory of natural distribution of xylitol, and provided early academic basis for the subsequent resource utilization of agricultural and forestry by-products.

1.2 Pioneers of Initial Preparation Process Theory (Early to Mid-20th Century: Process Embryonic Stage)

- ***Wavra (Western European chemical engineer)***:

  Early explorer of modern xylitol preparation technology. In 1942, he pioneered the high-pressure catalytic hydrogenation process for xylose, overcoming the defects of traditional sodium amalgam reduction method including excessive impurities, low purity and incapability of mass production. For the first time, he realized the

conversion from xylitol slurry to high-purity solid products, established the core process principle of modern xylitol production via catalytic hydrogenation, and provided critical technical ideas for subsequent industrial pilot production.

- ***Core European Chemical Research Team (Early to Mid-20th Century)***:

  Founder of the artificial preparation technology system. After the discovery of xylitol, the team carried out targeted research on two technical routes including chemical synthesis and plant hydrolysis, analyzed the hydrolysis mechanism of agricultural and forestry by-products such as birch wood, corn cob and sugarcane bagasse, and established complete working procedures including acid hydrolysis, neutralization, decolorization and crystallization. Plant hydrolysis extraction was confirmed as the mainstream early-stage process. The team also comprehensively measured the physical and chemical indicators of xylitol and verified its feasibility in food application, building the initial theoretical and experimental framework for xylitol preparation.

1.3 Research Groups for Industrialized Production Process Finalization (1950s-1960s: Industrial Landing Stage)

- ***Nordic Food and Chemical Research Team (Sweden/Finland, 1950s-1960s)***:

  Pioneer team of xylitol industrialization. Relying on abundant local birch resources in Northern Europe, the team solved key pain points of traditional processes such as low yield, excessive impurities, poor color and insufficient purity. It optimized core procedures including acid hydrolysis, catalytic reduction and advanced refining, improved reaction temperature, pressure and catalyst system, and completed the world's first industrial pilot test and mass production. The team finalized the first commercialized plant hydrolysis-catalytic reduction production process, transforming xylitol from laboratory samples to standardized industrial raw materials and officially launching the industrial era of xylitol. Meanwhile, it initially explored the insulin-independent metabolic characteristics of xylitol.

1.4 Authoritative Scientists for Core Functional Clinical Verification (1960s-1980s: Value Confirmation Stage)

- ***Kauko K. Mäkinen (Finland)***:

  Milestone scholar in xylitol functional research and founder of the international xylitol anti-caries theory. As a professor at the University of Turku in Finland, he led the world-famous Turku Sugar Studies from 1972 to 1975. Through large-scale controlled human clinical trials, he systematically proved for the first time that xylitol can inhibit the reproduction of oral Streptococcus mutans, block organic acid generation, reduce dental plaque accumulation and significantly lower caries incidence, as well as relieve dry mouth symptoms. His research results officially confirmed the core anti-caries function of xylitol, providing top-level clinical evidence for the

large-scale application of xylitol in oral care and sugar-free food sectors. He is universally recognized as the core founder of functional application of xylitol by global academic circles.

- ***Joint European and American Stomatology and Nutrition Research Team (1960s-1980s)***:

  Improvers of the xylitol functional system. Building on Professor Mäkinen's research results, the team conducted extensive in vitro experiments, animal experiments and multi-regional controlled human trials. It fully clarified the human metabolic pathway of xylitol, proved its extremely low glycemic index and insulin-independent metabolism suitable for diabetic patients. Combined with its low-calorie property, three core functional advantages of xylitol including anti-caries effect, low glycemic response and low calorie were formally established, defining the differentiated market positioning of xylitol products.

1.5 Expert Group for Global Safety Compliance System Establishment (1970s-1990s: Globalization Foundation Stage)

- ***Joint Safety Evaluation Expert Group of JECFA, FDA and EFSA (Global authoritative toxicology and nutrition scholars)***:

  Founder of the global xylitol compliance system. The team conducted comprehensive safety evaluations of xylitol, including acute toxicity, subchronic toxicity, chronic toxicity, genotoxicity, reproductive and developmental toxicity tests as well as human tolerance limit tests. It formulated clear safe daily intake dosage and industrial application specifications, confirming no potential safety risks of long-term xylitol consumption. The team promoted the certification and filing of xylitol by authoritative global institutions including the United Nations, the United States, the European Union and Japan, eliminating global market access barriers and building a unified global safety standard system, which supported the global popularization of xylitol.

1.6 Pioneers of Raw Material Expansion and Process Environmental Optimization (1980s-1990s: Industrial Expansion Stage)

- ***Core Forestry and Chemical Scholars from Northern Europe and Russia (1980s-1990s)***:

  Key promoters of large-scale industrial upgrading. The team broke the limitation of single birch raw materials, explored the resource utilization value of various agricultural and forestry wastes such as corn cob, rice husk, cottonseed hull and sugarcane bagasse, expanding raw material supply channels and cutting production costs significantly. Targeting the disadvantages of traditional acid hydrolysis including high pollution, strong corrosion and excessive by-products, the team innovated mild hydrolysis and high-efficiency catalytic hydrogenation processes to improve production environmental friendliness and raw material utilization rate, optimizing the traditional preparation system and driving the large-scale expansion of the global xylitol industry based on global agricultural and forestry resources.

1.7 Founders of Basic Xylitol Metabolism Research in China (1960s-1990s: Domestic Theoretical Breakthrough Stage)

- ***Zhang Shuzheng (1922—2016, Member of Chinese Academy of Sciences, China)**:*

  Pioneer of sugar alcohol metabolism research in China and the founder of domestic basic theoretical research on xylitol. As early as the 1960s, she took the lead in researching microbial metabolism mechanisms of xylose and xylitol in China, clarified the complete metabolic pathways of xylose and arabinose in Geotrichum candidum, purified and identified xylitol dehydrogenase and confirmed its inducible enzyme properties. Her research revealed the core mechanism of microbial xylitol synthesis, filling the domestic research gap in microbial metabolism of xylitol. It laid a solid theoretical foundation for subsequent domestic research on biological xylitol production, strain breeding and enzyme engineering improvement, making her a pioneer in China's biological manufacturing sector for xylitol.

1.8 Pioneers of Domestic Industrialization Technology Research in China (1970s-1990s: Domestic Industrial Development from Scratch)

- ***Senior Domestic Researchers in Light Industry and Food Industry (China)**:*

  Trailblazers of China's xylitol industry. When China's xylitol industry was completely blank and relied fully on imported products, the team tracked overseas technical systems, introduced core plant hydrolysis processes, and carried out comprehensive localization transformation adapting to domestic agricultural and forestry resources such as corn cob and crop straw. It solved a series of core technical bottlenecks including raw material pretreatment, hydrolysis formula adaptation for local raw materials, equipment corrosion prevention, crude product refining and purity improvement, and completed full verification of lab-scale and pilot-scale experiments. The team formulated early internal enterprise standards and local industrial standards, laying a solid foundation for the launch of China's first xylitol production line and the breakthrough of domestic independent production.

1.9 Leading Domestic Research Teams for Green Biological Processes and High-end Applications (Early 21st Century to Present: Global Leading Stage)

- ***Core Research Team, School of Food Science and Technology, Jiangnan University**:*

  Benchmark team for green manufacturing of sugar alcohols in China. Targeting the shortcomings of traditional chemical processes including high pollution and high energy consumption, the team took the lead in developing green preparation technologies such as biological enzymatic hydrolysis and microbial transformation, and optimized precision refining processes including membrane separation, continuous crystallization and ion exchange. These innovations greatly improved product yield and purity, reduced three-waste emissions, and led the transformation of China's xylitol industry from traditional chemical manufacturing to biological

manufacturing. The team has achieved fruitful results in high-purity refined products and compound application technologies.

- ***Core Research Team, School of Light Industry and Chemical Engineering, Dalian Polytechnic University:***

  Leading team for recycling utilization of agricultural and forestry resources. Focusing on the high-efficiency conversion technology of bulk agricultural by-products such as corn cob and crop straw, the team optimizes the whole-process technologies including hydrolysis, catalytic hydrogenation and by-product recovery, maximizes raw material utilization rate, and builds a low-carbon circular production system. It provides core technical support for cost reduction, efficiency improvement and large-scale capacity expansion of domestic xylitol production.

- ***Core Research Team, School of Food Science and Bioengineering, Qilu University of Technology:***

  Core force for industrial standardization and refined application of xylitol. The team leads the optimization of domestic xylitol detection methods, precise impurity control and product grading system, and participates in the formulation and revision of national and industrial standards throughout the process. It conducts in-depth research on refined application technologies and compound sweetener systems to expand application scenarios of xylitol, promoting the standardized, high-end and diversified development of the industry.

1.10 Core Domestic Engineer Groups for Industrialization and Global Market Promotion in China

- ***Senior Engineers in China's Sugar Alcohol Industry:***

  Core promoters of domestic xylitol industrialization and marketization. Undertaking domestic scientific research achievements, the team led the construction of large-scale industrial production lines, process scaling-up, mass production debugging and equipment iteration. It completely broke overseas technological monopoly and realized full import substitution. The team developed multi-specification products including food-grade, pharmaceutical-grade, daily chemical-grade and oral special-grade xylitol, provided professional downstream application technical services, promoted full-scenario popularization of xylitol, and supported China's xylitol industry to grow from scratch to a global leader.

2. Core Research Institutions and University Teams

2.1 Nordic Institute of Forestry and Chemical Engineering (Sweden / Finland)

The birthplace of global xylitol industrialization technology and a core early-stage research institution. Relying on high-quality local birch forest resources in Northern Europe,

the institute developed the world's first mature plant hydrolysis-catalytic hydrogenation mass production process and formulated the first batch of industrial product quality standards and application specifications. It has long conducted in-depth research on basic mechanism analysis, process optimization and functional verification of xylitol. Its technical system, detection methods and safety data have served as universal global industrial benchmarks in the early industrialization stage, dominating global technological iteration of xylitol in that period.

2.2 School of Food Science and Technology, Jiangnan University (China)

Top domestic research platform for sugar alcohol industry and core innovation hub for green manufacturing. Focusing on four core research directions including biological transformation, green preparation, precision refining and compound application of xylitol, the university team continuously solves environmental bottlenecks of traditional processes and develops new low-carbon, high-efficiency and pollution-free production technologies. It takes a leading position globally in high-purity pharmaceutical-grade xylitol, compound functional sweetener products and high-end downstream formula development, acting as a core driving force for technological upgrading and high-end product iteration of China's xylitol industry.

2.3 School of Light Industry and Chemical Engineering, Dalian Polytechnic University (China)

Characteristic domestic research platform for recycling utilization of agricultural and forestry by-products. Specializing in the high-efficiency conversion and circular utilization of bulk agricultural wastes such as corn cob and crop straw, the team optimizes the whole-process technologies including xylitol hydrolysis, hydrogenation, by-product recovery and energy conservation, and builds a resource-circular production model. It provides critical technical support for China to build a large-scale, low-cost and sustainable xylitol industrial system based on domestic agricultural and forestry resources.

2.4 School of Food Science and Engineering, Qilu University of Technology (China)

Key domestic research institution for industrial standardization, quality control and application technology of xylitol. The school leads the optimization of domestic xylitol detection system, product grading, quality traceability and safety risk assessment, and deeply participates in the drafting and revision of national food safety standards and industrial production specifications. It conducts targeted research on downstream scenario adaptation technologies to promote the refined, specialized and diversified development of xylitol industry.

Part 2: R&D History of Xylitol

Stage 1: Substance Discovery and Basic Exploration (Late 19th Century - 1940s)

With the rapid development of modern organic chemistry and carbohydrate chemistry, researchers launched systematic analysis on polyol components in plant cell walls. In 1891, German chemist Emil Fischer and his assistant Rudolf Stahel first separated and purified xylitol and resolved its molecular structure from hydrolyzed birch lignin products. Meanwhile, French scholar Bertrand independently extracted xylitol syrup from crop straws. Their joint research completed the first scientific discovery and naming of xylitol.

From 1900 to 1940, European and American academic circles confirmed that xylitol widely exists in natural carriers such as corn cob, crop straw, fruits and fungi. A complete set of physical and chemical parameters including sweetness, melting point, solubility, hygroscopicity, thermal stability and acid-base resistance were determined. Researchers confirmed its core advantages of mild sweet taste similar to sucrose and excellent adaptability to food processing. In 1942, Wavra invented the high-pressure catalytic hydrogenation process, breaking through bottlenecks of traditional purification technologies and providing key technical ideas for subsequent industrial exploration.

In this stage, only small-scale laboratory micro-extraction was available. Limited natural raw material content, extremely high purification costs and low output restricted xylitol to academic research only, with no capacity for industrial mass production or commercial application.

Stage 2: Process Exploration and Industrial Pilot Production (1940s - Late 1960s)

Driven by the upgrading of global chemical industry and shortage of sucrose resources after World War II, the world accelerated R&D on artificial mass production technology of xylitol, entering a critical period for process breakthroughs.

From 1940 to 1955, the industry eliminated complicated and unsafe pure chemical synthesis methods, and confirmed plant acid hydrolysis-catalytic reduction as the mainstream technical route. Nordic research teams continuously optimized core working procedures including hydrolysis, neutralization, hydrogenation and primary crystallization to solve basic problems restricting mass production.

From 1955 to 1969, Finland and Sweden built the world’s first formal xylitol industrial production lines relying on local birch resources. The initial production lines had limited capacity and high product prices, and xylitol was only applied in niche scenarios such as pharmaceutical products and special dietary food for patients. Meanwhile, breakthroughs were made in animal metabolism experiments, proving that xylitol metabolism does not rely on insulin and exploring its unique application value for diabetic patients.

Stage 3: Functional Verification, Process Finalization and Global Compliance (1970s - Early 1990s)

After the formalization of industrial production processes, global research focus shifted to clinical efficacy demonstration, toxicological safety evaluation and global regulatory compliance construction.

From 1972 to 1975, Finnish scholar Kauko K. Mäkinen led the classic Turku Sugar Studies, which authoritatively proved the anti-caries, dental plaque inhibition and dry mouth relief effects of xylitol for the first time. Subsequent multi-dimensional controlled trials conducted by European, American and Nordic research teams improved its functional system including low glycemic response and low calorie. The application scope of xylitol expanded from pharmaceutical products to oral care products such as chewing gum, lozenges and toothpaste.

From 1975 to 1992, authoritative global institutions including JECFA, FDA and EFSA completed comprehensive toxicological safety assessments of xylitol and formulated unified safe intake standards, confirming the safety of long-term consumption. Xylitol obtained food additive access qualifications in dozens of countries and regions worldwide, marking the completion of a unified global compliance system and unblocking global market channels. Enterprises in Northern Europe and Russia expanded production continuously, and xylitol products were widely popularized in European, American, Japanese and South Korean markets.

Stage 4: Technology Introduction and Domestic Industrial Budding (Late 1970s - 2000)

In this stage, China relied fully on imported xylitol with extremely high prices. Xylitol was only used in a small amount in high-end pharmaceutical products and imported oral care products, while the domestic consumer market remained blank.

In the 1960s, Academician Zhang Shuzheng took the lead in researching microbial metabolism mechanisms of xylitol in China and laid the foundation of domestic basic theoretical system. Starting from 1978, domestic research institutes in light industry and food industry tracked overseas cutting-edge technologies and carried out independent R&D. Combining domestic resource advantages of corn cob and crop straw, they introduced plant hydrolysis processes and completed targeted localization transformation, solving core technical bottlenecks such as raw material adaptation, equipment corrosion prevention and refined purification, and finishing lab-scale and pilot-scale experiments.

In the mid-to-late 1980s, China’s first xylitol industrial production line was put into operation, realizing the breakthrough of domestic independent production from scratch and initially breaking the import monopoly. Early domestic products fell behind international counterparts in quality with limited production capacity, mainly serving the mid-to-low-end market. In the 1990s, China formulated internal enterprise standards and local industrial standards, incorporated xylitol into the domestic food additive management system, and the domestic xylitol industry entered the budding stage.

Stage 5: Process Upgrading, Capacity Expansion and Import Substitution (2000 - 2015)

After 2000, the global sugar reduction trend boosted the booming demand for sugar-free food and oral care products, bringing a golden period of technological upgrading and capacity expansion for China's xylitol industry.

Domestic universities and industrial enterprises carried out collaborative innovation. Targeting the disadvantages of traditional acid hydrolysis including high pollution and low yield, they optimized refining processes such as catalytic hydrogenation, ion exchange, membrane separation and continuous crystallization. The purity, stability and taste of domestic xylitol products caught up with international leading levels comprehensively. Supported by abundant and low-cost domestic agricultural and forestry raw materials including corn cob and sugarcane bagasse, production costs dropped sharply, forming prominent cost-performance advantages.

From 2000 to 2015, domestic industrial scale expanded steadily with mature industrial clusters and continuous capacity release, realizing full import substitution. Xylitol products were applied in full scenarios covering food, beverage, baking, daily chemical products and feed. China improved national standards and detection specifications continuously, optimizing industrial quality control and production systems. China grew into the world's core production base of xylitol.

Stage 6: Green Transformation, Diversified Technology and Global Leading Position (2015 - Present)

Since 2015, tightening global environmental policies and upgrading high-end health consumption demand have driven the xylitol industry into a new stage featuring green manufacturing, high-end segmentation and global market leadership.

- ***Technological Dimension***:

  Green processes including biological enzymatic hydrolysis, mild hydrolysis, three-waste recycling and intelligent continuous production have been widely applied to replace traditional high-pollution chemical processes. Supported by synthetic biology and advanced separation technologies, raw material utilization rate and product purity have been further improved to realize low-carbon and high-efficiency production, completing the transformation from traditional chemical manufacturing to modern biological manufacturing. Industrial players launched refined product grading and developed differentiated products such as ultra-high-purity pharmaceutical-grade, oral special-grade and high-end daily chemical-grade xylitol.

- ***Capacity and Market Dimension***:

  China has become the world's largest producer and exporter of xylitol, taking leading global advantages in production capacity, supply chain, cost and technology. Chinese products are sold worldwide and occupy the majority share of the global market. Leading domestic enterprises have completed full industrial chain layout, realizing

integrated development covering raw material supply, production and downstream application technical services.

- ***Application Dimension***:

  Breaking the limitation of traditional application scenarios, xylitol has been expanded to emerging tracks including skin care products, health supplements, animal nutrition and bio-based materials, improving product added value and extending the whole industrial life cycle.

Part 3: Commercial Development History of Xylitol

The commercial development of xylitol covers eight core processes including substance discovery, process iteration, functional certification, regulatory approval, overseas market popularization, domestic technological breakthrough, capacity expansion and global market leadership. Evolving from a rare laboratory substance and high-end pharmaceutical raw material to one of the most widely used and safest functional sugar alcohols worldwide, its commercial development can be divided into six stages.

Stage 1: Initial Commercialization and Niche Market Development in Northern Europe (Late 1960s - Late 1970s)

The launch of the world's first xylitol industrial production line in Northern Europe in the late 1960s marked the official start of xylitol commercialization. In the initial stage, production capacity was concentrated in Finland and Sweden relying on local birch raw materials, with limited output, high production costs and high terminal prices. Restricted by high prices and low market awareness, xylitol was only applied in niche high-end scenarios including special dietary food for diabetic patients, clinical pharmaceutical preparations and high-end oral care products. The global market scale remained small, and overseas market promotion progressed slowly.

Stage 2: Functional Empowerment and Overseas Market Popularization (1980s - Mid-1990s)

Supported by Professor Mäkinen's authoritative clinical research, the anti-caries and blood sugar control functions of xylitol were globally recognized. Combined with the completion of global safety regulatory systems, the commercial development of xylitol achieved a key turning point. The market boomed first in Europe, America, Japan and South Korea, and xylitol became a core functional ingredient for chewing gum, sugar-free candy, toothpaste and mouthwash. It also gradually penetrated into sugar-free beverage, low-sugar baking and special dietary food sectors. Overseas enterprises optimized product specifications and launched diversified products with different purity levels. By the mid-1990s, xylitol had become one of the mainstream functional sweeteners in developed countries.

Stage 3: Domestic Technological Breakthrough and Preliminary Market Enlightenment (Mid-1990s - 2005)

Domestic xylitol production capacity was released steadily starting from the mid-1990s, and domestic products officially entered the local market. Early domestic products focused on cost-performance to seize the mid-end market including common food, ordinary oral care products and basic pharmaceutical products, while the high-end market was still monopolized by imported Northern European products. Domestic consumers had low recognition of xylitol, and application scenarios were limited to chewing gum and ordinary candy.

After 2000, domestic health awareness awakened, driving steady growth in demand for sugar-free and anti-caries products. Domestic industrial players optimized production processes, expanded capacity and improved application service systems continuously. The domestic xylitol market completed preliminary enlightenment and entered a stable growth track.

Stage 4: Rapid Capacity Expansion and Comprehensive Market Popularization (2005 - 2015)

Starting from 2005, the global sugar reduction trend broke out comprehensively, and low-sugar and sugar-free formulas became mainstream trends in China's food industry, bringing a high-growth golden period for xylitol. Relying on abundant domestic corn cob resources, China achieved concentrated capacity expansion. Large-scale production greatly reduced market prices and promoted the popularization of xylitol among mass consumers. Xylitol achieved full coverage of food industry application scenarios. Meanwhile, industrial standards were improved continuously, backward production capacity was phased out, and industrial concentration increased steadily. Domestic products realized full import substitution and began to be exported in batches to the global market.

Stage 5: China's Capacity Leadership and Global Industrial Pattern Restructuring (2015 - 2020)

After 2015, China's xylitol industry achieved comprehensive upgrading in technology, production capacity and supply chain, surpassing traditional Northern European producing regions to become the world's largest production and export base. The global industrial pattern was completely restructured: traditional overseas manufacturers reduced bulk production capacity and focused on high-purity customized high-value-added products; Chinese players dominated the global mainstream market relying on comprehensive advantages in raw materials, cost, production capacity and full product categories, becoming the core pillar of the global xylitol supply chain. Industrial competition shifted from single price competition to comprehensive competition focusing on product quality, technology and application services.

Stage 6: Green Upgrading, Cross-border Application and Long-term Trend Outlook (2020 - Present)

Currently, global health awareness, low-carbon development and sustainable development have become the mainstream themes of the industry, and the xylitol industry has entered a new stage of high-quality development. The future development trends are clarified as follows:

1. Technological Development Trend

Green biological manufacturing will remain the core development direction. Low-carbon processes including biological enzymatic hydrolysis, microbial transformation, continuous intelligent production and three-waste recycling will fully replace traditional high-pollution chemical processes. Supported by synthetic biology and advanced separation and purification technologies, the industry will further improve raw material utilization rate, product purity and production efficiency while cutting energy consumption and carbon emissions. Intelligent manufacturing and automatic process control will be fully popularized to promote refined and modernized upgrading of the whole industry.

2. Product Development Trend

Xylitol products will develop towards high-end, segmented and specialized directions, focusing on high-value-added products such as injection-grade, ultra-high-purity pharmaceutical-grade and high-end skin care-grade xylitol. Specialized products adapted to segmented scenarios including beverage, baking, oral care and feed will be developed continuously. Sweetener compounding technology will be iterated constantly; compound formulas combining xylitol with erythritol, steviol glycosides and monk fruit sweetener will optimize taste and reduce costs to build diversified sweetener systems.

3. Functional and Application Trend

Based on in-depth nutrition and physiological research, researchers will continuously explore new application value of xylitol in intestinal health, skin repair, animal nutrition and bio-based materials, breaking traditional application boundaries and realizing cross-border industrial expansion. This will further improve product added value and extend the industrial life cycle of xylitol.

4. Global Market Trend

China will further consolidate its leading global position, transforming from pure product export to technology export, standard export and overall application solution export. Driven by the long-term global sugar reduction and healthy consumption trend, xylitol will maintain steady market growth relying on its core advantages of high safety, pleasant taste and multi-functional properties, and remain one of the mainstream functional sweetener ingredients worldwide.