

# Applications of precision fermentation technology: From lab to market impact

*A comprehensive analysis of industrial applications and emerging trends in sustainable biotechnology*

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## Executive summary

Precision fermentation is emerging as a cornerstone of sustainable manufacturing. By programming microbes to produce high-value molecules in controlled bioreactors, industries can achieve consistent quality, scalability, and environmental responsibility. Market projections show rapid growth from USD 4.25 billion in 2024 to over USD 267 billion by 2035, with annual growth rates exceeding 40 percent. (1) Market size estimates vary widely depending on whether food, non-food industrial applications, geographic scope, and time horizon are included in the analysis.

This paper provides a comprehensive view of precision fermentation in non-food applications. It explores market drivers, scientific principles, industrial applications, and sustainability benefits. It also examines future trends and includes a case study of HeiQ Life Sciences' precision fermentation lab in Switzerland.

In this paper, the term “microbes” is used as a general reference to microorganisms such as bacteria, yeast, and fungi used as production hosts in precision fermentation.

## 1. Introduction and market context

Precision fermentation is not new to biotechnology, and its role is expanding quickly. Initially associated with alternative proteins, it is now increasingly used to produce high-value ingredients for healthcare, cosmetics, textiles, packaging, and cleaning applications. In controlled bioreactors, microbes that occur naturally in the environment are used as production hosts. The innovation lies in the controlled fermentation process, which enables consistent and scalable molecule production.

Global investment in industrial biotechnology is accelerating. The European Commission has positioned life sciences and biomanufacturing as strategic priorities, including fermentation-based approaches. (4) North America continues to lead in commercial scale-up, supported by venture capital and public programs. Together, these trends are widening the pipeline of fermentation-derived ingredients and accelerating adoption across non-food sectors, which sets the context for the market drivers and challenges described in the next section. (1, 2)

## 2. Market drivers and challenges

Precision fermentation is gaining momentum due to several converging market forces.

**Sustainability mandates** are driving industries to seek alternatives to petrochemical and agricultural extraction. Governments and organizations are setting carbon reduction targets, and precision fermentation supports these goals by enabling the use of renewable feedstocks and reducing waste. For example, the European Union's Green Deal supports the development of a circular bioeconomy, including biological manufacturing. (4) In North America, biological manufacturing is being addressed through a combination of biotechnology, biomanufacturing, and supply chain resilience initiatives, while in parts of Asia policy frameworks promoting bioeconomy development, industrial modernization, and supply chain resilience are also supporting the adoption of biological manufacturing processes.

**Regulatory frameworks** in the European Union and the United States continue to be applied and refined to address safety, quality, and labeling requirements for fermentation-derived ingredients, particularly in cosmetics and cleaning applications. In the European Union, the revised Detergents and Surfactants Regulation published in 2026 strengthens requirements related to manufacturing controls, ingredient transparency, and market surveillance, including for products containing microorganisms, while maintaining a risk-based, post-market compliance approach rather than introducing blanket pre-market authorization. The European Commission's investment in fermentation technologies reflects a broader policy trend toward supporting environmentally responsible manufacturing practices. In the United States, fermentation-derived ingredients are regulated within established, risk-based frameworks. Current regulatory activity focuses on clarifying oversight responsibilities, safety substantiation, manufacturing controls, labeling, and post-market enforcement for products derived from microbial processes.

In Asia, regulatory approaches to fermentation-derived ingredients vary by country. China has identified biomanufacturing and synthetic biology as strategic priorities within its national bioeconomy plans, supporting industrial scale-up through coordinated policy and regulatory oversight. Japan applies established, product-based regulatory frameworks to fermentation-derived ingredients, with a strong emphasis on safety, quality, and labeling. South Korea has focused on building biomanufacturing and synthetic biology infrastructure as part of its national technology strategy, enabling rapid development and scale-up within existing regulatory structures.

**Consumer demand** for transparency, ethical sourcing, and sustainability is reshaping product development. Consumers show a growing preference for products made with renewable resources and minimal environmental impact. This trend is especially strong in cosmetics, healthcare, and textiles, where ingredient origin and production methods influence purchasing decisions.

**Challenges addressed by precision fermentation** include overcoming the variability and limitations of traditional extraction. Plant and animal sources vary due to seasonal

changes, supply chain disruptions, and inconsistent yields. Purification processes for these sources are often complex and costly, and scaling up production may be challenging. Precision fermentation offers a solution by providing a controlled, reproducible process that delivers consistent quality and scalability.

Industries adopting precision fermentation are better positioned to meet regulatory requirements, respond to consumer preferences, and achieve sustainability targets. The technology also enables innovation, allowing companies to develop new products and functionalities that were previously unattainable with conventional methods.

### 3. Scientific principles and technological advances

Precision fermentation is built on advances in synthetic biology, genetic engineering, and process control. Microorganisms such as yeast, bacteria, and fungi are selected or engineered to produce specific molecules, including proteins, enzymes, and biopolymers.

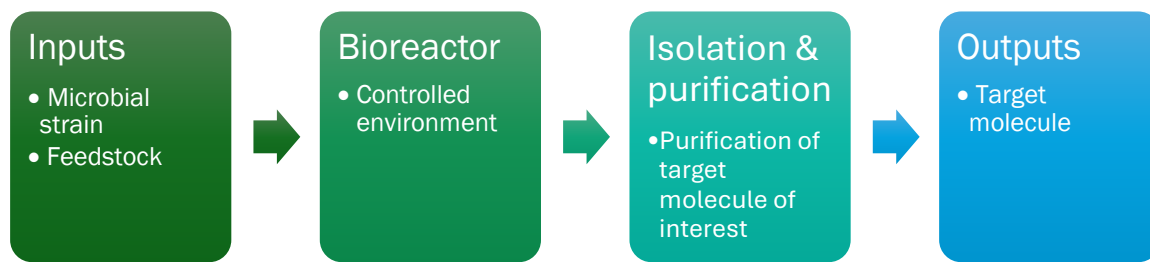
**Strain engineering** is a critical step. Scientists use tools like CRISPR and machine learning to modify microbial genomes, optimizing metabolic pathways for higher yields, stability, and efficiency. This process can involve inserting genes that encode for desired molecules, deleting genes that cause unwanted byproducts, and fine-tuning regulatory elements to control expression levels.

**Bioreactor control** ensures that fermentation conditions are optimal for microbial growth and product formation. Parameters such as temperature, pH, oxygen concentration, and nutrient supply are monitored and adjusted in real time. Advanced bioreactors are equipped with sensors and automation systems that maintain precise conditions, minimizing variability and maximizing productivity.

**Omics integration**, including genomics, transcriptomics, proteomics, and metabolomics, provides a comprehensive understanding of microbial behavior. By analyzing data from these sources, researchers can identify bottlenecks in production, troubleshoot issues, and further refine strains and processes.

**Process optimization** extends beyond the laboratory. Scale-up from bench to pilot and industrial scale requires careful validation to ensure that engineered strains perform consistently in larger bioreactors. Downstream processing, including purification and formulation, is also optimized to deliver high-purity products suitable for commercial applications. Integration of omics data enables identification of metabolic bottlenecks and guides strain optimization, improving yield stability during scale-up.

Figure 1: Precision fermentation process flow



This process enables the production of molecules that are identical to those found in nature, with greater consistency, purity, and scalability than traditional extraction methods.

## 4. Industrial applications

Precision fermentation is transforming multiple industries by enabling the production of high-value ingredients and materials.

### Healthcare:

Bacterial cellulose produced via fermentation is used in advanced wound care products. Its high purity, mechanical strength, and biocompatibility make it suitable for advanced wound dressings requiring moisture management and structural integrity. (6) Enzymes produced by engineered microbes are used in diagnostics, therapeutics, and medical devices, providing defined activity and safety profiles.

### Cosmetics:

Fermentation-derived ingredients such as ectoine and collagen are valued for their stability, hydration properties, and sustainability. Ectoine, produced by extremophilic bacteria, is valued for its stability and role in formulations designed to support skin hydration and stress protection. (5) Collagen produced by yeast or bacteria offers a renewable alternative to animal-derived sources, supporting consistent and sustainable product development.

### Textiles and packaging

Precision fermentation enables production of enzymes, polymers, and fibers for textiles and packaging in the following ways:

- **Fiber feedstock:** Bacterial cellulose can be produced directly into filaments or pellicles and used as feedstock for yarns. Researchers have demonstrated that bacterial cellulose can be grown into filaments, enabling spinning and weaving into woven textiles. (9)
- **Functional yarns:** In 2025, Yilu Xu and colleagues at Jiangnan University reviewed bacterial cellulose-derived functional yarns, noting their renewable and carbon-neutral nature, superior mechanical strength, easy processing, and suitability for nonwovens, flexible wearables, and textile reinforcement. (9)

- **Nonwoven fabrics:** Bacterial cellulose sheets form nonwoven meshes that offer strong tensile strength and abrasion resistance, with potential applications in nonwoven technologies. (10)

Fermentation-derived polymers also support biodegradable packaging materials with strong barrier properties.

### Cleaning:

Precision fermentation is transforming the cleaning industry by enabling the production of biosurfactants and supporting the development of probiotic cleaning solutions.

Probiotic cleaning uses beneficial live microbes, produced via fermentation, that are incorporated into cleaning products to support microbiome-aligned cleaning approaches, enhanced biodegradability, and reduced environmental impact.

- **Probiotic cleaning** is based on the principle of introducing selected beneficial bacteria to surfaces. These probiotics, once applied, help to maintain a balanced microbial ecosystem, outcompete undesirable microbes, and contribute to long-lasting cleanliness. This approach is increasingly supported by modern hygiene science, which recognizes the importance of preserving healthy microbial communities in homes, workplaces, and public spaces. For example, a study conducted at Charité–Universitätsmedizin Berlin demonstrated that probiotic cleaning protocols using live bacteria reported measurable beneficial shifts in surface microbiome composition compared to conventional disinfectants and detergents. (11)
- **Synbiotic cleaning** represents an enhanced formula, combining live probiotics with prebiotic nutrients that help these beneficial microbes thrive on surfaces. The addition of prebiotics further enhances the effectiveness of probiotic cleaning by supporting the growth and activity of the introduced bacteria.
- **Biosurfactants** produced by engineered microbes via precision fermentation offer several advantages:
  - **Biodegradability:** Biosurfactants naturally break down, minimizing environmental impact and persistent residues.
  - **Low toxicity:** They are gentle on surfaces and suitable for household and industrial cleaning.
  - **Effective cleaning:** Biosurfactants efficiently remove oils, dirt, and organic matter, even under challenging conditions such as hard water or low temperatures.

The controlled fermentation process ensures consistent quality and purity. Precision fermentation enables scalable production of tailored biosurfactants and probiotic blends, supporting the development of cleaning products designed for sustained performance and environmental sustainability.

Table 1: Example applications of precision-fermented ingredients by sector and key benefits

Sector	Product	Ingredient	Standard characteristics	Enhanced characteristics
<b>Healthcare</b>	Bandage	Bacterial cellulose	Synthetic or plant-derived polymer dressings with variable structure and purity	Consistent cellulose structure and material properties
	Wound care spray	Enzymes or microbial actives	Chemically synthesized or mixed-origin ingredients with batch variability	Biodegradable actives with defined and reproducible activity
<b>Cosmetics</b>	Face moisturizer (daily hydration cream)	Ectoine	Humectants and botanical extracts with variable composition	Consistent ectoine quality for repeatable formulations
	Firming serum (collagen-based skin feel)	Precision-fermented collagen	Animal-derived collagen or synthetic peptides	Animal-free collagen with consistent purity and supply
<b>Textiles</b>	Denim finishing (biopolishing)	Cellulase enzymes	Pumice stone washing or harsh chemical finishing	Controlled enzymatic finishing with improved process consistency
	Nonwoven reinforcement layer (for performance textiles)	Bacterial cellulose (fibers or sheets)	Petroleum-derived synthetic reinforcement fibers	Renewable cellulose reinforcement with strong mechanical performance
<b>Packaging</b>	Paper cup or food-service box with barrier layer	Bacterial cellulose-based barrier coating	Polyethylene coatings for liquid and grease resistance	Bio-based barrier with reduced fossil-plastic reliance
	Flexible packaging film	Biopolymers	Multilayer fossil-based films (PE/PET)	Biodegradable polymers with tunable material properties
<b>Cleaning</b>	Multi-surface cleaner	Biosurfactants (e.g. sophorolipids or rhamnolipids)	Petrochemical surfactants	Biodegradable surfactants with consistent performance
	Bathroom or floor cleaner	Probiotic or synbiotic actives	Conventional detergent-only formulas	Formulations incorporating microbial actives

## 5. Performance and sustainability benefits

Precision fermentation offers a set of performance and sustainability advantages that support industry transformation.

### Consistent quality:

Controlled bioreactor environments ensure that products are manufactured with minimal batch-to-batch variability. This consistency is important for applications in healthcare, cosmetics, and food, where purity and reproducibility are critical.

### Lower carbon footprint:

Using renewable feedstocks such as sugars from agricultural waste or non-food crops, precision fermentation reduces greenhouse gas emissions compared to petrochemical synthesis or animal extraction. The process also generates less waste and uses less water.

### Batch-to-batch reproducibility:

Genetic stability of engineered strains and precise process control result in reliable production outcomes. This reproducibility can support regulatory processes and quality assurance.

### Scalable infrastructure:

Fermentation processes can be scaled from laboratory to industrial volumes, supporting commercial production and market expansion.

Table 2: Feature and benefit

Feature	Benefit
<b>Controlled bioreactor</b>	Enables improved batch consistency under controlled process conditions <i>Example: producing ectoine with a consistent impurity profile and concentration targets across batches, supporting repeatable cosmetic formulation behavior.</i>
<b>Renewable feedstocks</b>	Can support reduced environmental impact, depending on feedstock and energy sources <i>Example: using sugar-based feedstocks (including suitable side streams such as molasses) rather than petrochemical inputs or animal-derived raw materials</i>
<b>Genetic stability</b>	Supports reproducible production when strain stability is maintained <i>Example: a production strain engineered for collagen expressions that maintain output across repeated fermentations, supporting predictable yields and quality testing.</i>
<b>Scalable infrastructure</b>	Enables scale-up from pilot to industrial volumes with appropriate validation <i>Example: scaling bacterial cellulose production from lab vessels to pilot bioreactors while keeping fiber structure and mechanical performance within specification.</i>

**Environmental benefits** can include reduced water use, minimal waste generation, and biodegradable outputs. These advantages align with global sustainability objectives and contribute to circular manufacturing approaches.

## 6. Outlook and innovation trends

The future of precision fermentation is shaped by ongoing innovation and expanding market opportunities.

**AI-driven strain optimization** is accelerating the development of microbial factories. Machine learning algorithms analyze large datasets to identify genetic modifications that improve yield, stability, and efficiency. This approach shortens development timelines and can increase the likelihood of commercial success.

**Integration with synthetic biology** is enabling the design of novel metabolic pathways and the production of molecules that were previously inaccessible. Synthetic biology tools allow for the assembly of complex biosynthetic routes, expanding the range of products that can be manufactured via fermentation.

**Expansion into materials science and specialty chemicals** is creating opportunities in new markets. Precision fermentation is being used to produce specialty polymers, adhesives, and coatings with tailored properties for industrial applications. (2, 3)

**Global investment and collaboration** are driving scale-up and commercialization. Partnerships between biotechnology companies, academic institutions, and industry leaders are fostering innovation and facilitating market entry.

**Regulatory evolution** is supporting the adoption of fermentation-derived products. Governments are updating guidelines to clarify approval processes and encourage sustainable manufacturing.

As precision fermentation continues to evolve, it will play a central role in enabling industries to meet performance, sustainability, and regulatory objectives.

## 7. Case study: HeiQ precision fermentation lab

In 2025, HeiQ Life Sciences has established a dedicated precision fermentation laboratory in Schlieren, Zurich, at the heart of Switzerland's biotech cluster. This facility exemplifies how precision fermentation can be leveraged to accelerate innovation and support sustainable product development across multiple sectors.

### Laboratory capabilities:

The HeiQ precision fermentation lab is equipped for microbial strain development, process optimization, pilot-scale validation, and pre-commercial scale-up. The team applies advanced genetic engineering and bioprocess control to create robust microbial strains capable of producing high-value molecules with consistent quality.

### Research focus:

Current projects include the development of postbiotic actives for hygiene and cleaning, bacterial cellulose for advanced wound care, and synbiotic formulations designed to help maintain balanced microbial ecosystems on surfaces. These initiatives are driven by a commitment to sustainability, performance, and regulatory compliance.

**Collaboration and partnerships:**

HeiQ Life Sciences collaborates with global partners in healthcare, cosmetics, textiles, and environmental sectors. The laboratory works closely with the biotechnology departments of leading research institutes and universities, including ETH Zurich and ZHAW (Zurich University of Applied Sciences). These collaborations foster knowledge exchange, joint research projects, and access to cutting-edge scientific expertise. The laboratory's flexible infrastructure supports co-development projects, custom formulation services, and technical support for regulatory documentation and market entry. By working closely with industry leaders and academic partners, HeiQ Life Sciences support the transition from laboratory research to commercial scale.

**Innovation and impact:**

The HeiQ precision fermentation lab illustrates how companies can bridge the gap between discovery research and industrial application. By integrating scientific expertise, advanced infrastructure, and a collaborative approach, HeiQ Life Sciences is contributing to the transformation of traditional manufacturing processes and the adoption of sustainable, science-driven solutions.

**8. Conclusion**

Precision fermentation is influencing the landscape of industrial biotechnology. Its ability to deliver high-purity, scalable, and sustainable solutions positions it as a key enabler of future manufacturing across healthcare, cosmetics, textiles, packaging, and cleaning sectors. Companies investing in precision fermentation today are well positioned to contribute to the transition toward circular, science-driven industries that meet the demands of regulators, consumers, and global sustainability goals.

The ongoing evolution of genetic engineering, bioprocess control, and data-driven optimization will continue to expand the possibilities of precision fermentation. As more industries adopt these technologies, collaboration and investment will support ongoing innovation and market development.

HeiQ Life Sciences' precision fermentation lab demonstrates how dedicated research, advanced infrastructure, and strategic partnerships can accelerate the development and commercialization of next-generation products. By embracing precision fermentation, organizations can unlock new opportunities for performance, sustainability, and market differentiation.

## Footnotes

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