McKinsey & Company

Agriculture Practice

Ingredients for the future: Bringing the biotech revolution to food

Fermented ingredients could alter the food landscape faster than once thought. However, new business models are needed for the $100 billion to $150 billion opportunity in fermented novel proteins.

by Daniel Aminetzah, John Levene, and Tom Brennan, with Kate Toews



March 2025

New biological technologies are sweeping across industries and unlocking possibilities for food.[1] Fermentation, a type of bioprocessing, allows food producers to make proteins and other ingredients using microbes rather than animals, significantly reducing land use and emissions from animal agriculture while increasing reliability and food security.

Fermented novel proteins could make up about 4 percent of total protein production by 2050, an annual market of $100 billion to $150 billion, with variability based on climate policies and the pace of technological development. Advancements in fermentation technology also stand to benefit other industries such as chemicals and materials.

Before novel proteins can take off, fermentation technology will need to scale. Most novel-ingredients players today have production costs that are an order of magnitude higher than the cost of the production of traditional protein, which are typically in the range of $2 to $15 per kilogram. To bring down price points through economies of scale, our projections show fermented-novel-ingredients players will need to invest more than approximately $250 billion cumulatively by 2050 to expand capacity.

In this article, we explore how the food industry can accelerate the shift to fermentation-derived ingredients, most notably proteins. To get there, incumbents, start-ups, and investors can improve fermentation production processes and bioreactor technology to reduce costs, make new products that are compelling to consumers, and bring partners together to scale the industry.

The potential for novel ingredients

The potential market for fermented-protein products is expected to be $100 billion to $150 billion by 2050 (Exhibit 1).[2] This opportunity has spurred traditional-fermentation players, food giants, sovereign wealth funds, and others to invest more than $4 billion of capital in precision and biomass fermentation over the past five years.[3]

The high interest in novel foods is due to their ability to augment traditional food production. For proteins in particular, the global market today is sizable, at approximately $3.0 trillion, and is estimated to grow to approximately $3.5 trillion by 2050. However, increasing feed prices, climate volatility, and disease are challenging animal agriculture's ability to support the nutrition needs of the growing global population.

Novel ingredients produced through bioprocessing are a way to mitigate these risks (see sidebar "About fermentation and cultivation of cell cultures"). Because fermentation takes place in a synthetic environment (bioreactors), manufacturing is both controlled and modular, increasing geographic flexibility and reducing exposure to weather, supply chain, and disease-related disruptions in the traditional food and agriculture value chain. In addition, fermentation requires a smaller land footprint than traditional agriculture, making it a powerful option for building greater food security.

Scale drivers for the future of food

Before the novel-ingredients industry can help make food systems more sustainable and resilient, it needs to be scaled up significantly. However, existing capacity to support scale-up is limited, and contract manufacturing organizations (CMOs) often have margin expectations that are not in line with food manufacturing industry standards, often making them unviable for companies looking for more capacity. Although several new capacity additions have been announced, others have fallen by the wayside due to macroeconomic factors.

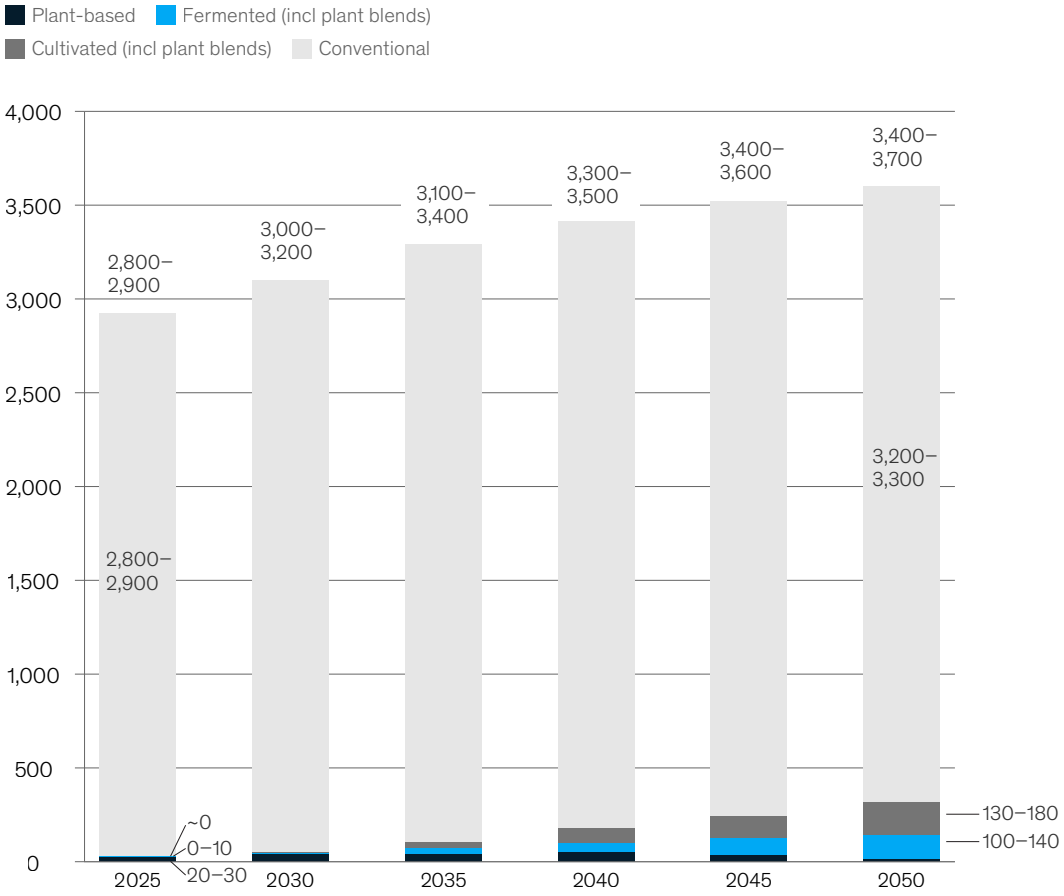
Building more capacity isn't the only challenge. The underlying technology and processes need to be developed and improved. The opportunities and risks of novel ingredients are still being investigated, and incumbents, start-ups, and investors alike are in the process of allocating capital expenditures, keeping stock of new developments, and understanding customer needs.

[1] For more on the Bio Revolution, see *The Bio Revolution: Innovations transforming economies, societies, and our lives*, McKinsey, May 13, 2020.
[2] Protein market segments include ruminant (beef, lamb, and goat), poultry (chicken and turkey), monogastric (pork), fish, dairy, and eggs. Blended-product sales that include any fermented or cultivated ingredient were fully allocated to their respective biotech category. In other words, the sale of a hybrid product using both plant and cultivated ingredients is considered "cultivated" for end-product sales. The noticeable drop in plant-based product sales should therefore be seen as driven in significant part by the increase in blended-product sales.
[3] *Emerging sustainable investing opportunities: Cultivated protein*, PitchBook, September 15, 2023.

Exhibit 1

Fermented novel proteins could account for approximately 4 percent of the global protein market by 2050.

Global protein market size, median adoption scenario,[1] $ billion



Note: All figures are approximate and may not sum to totals, because of rounding.
[1]Based on a 2°C warming scenario, in 2020 dollars. Figures reflect median of 2 growth scenarios. Protein market segments include ruminant (eg, beef, lamb, or goat), poultry (eg, chicken or turkey), monogastric (eg, pork), fish, dairy, and eggs. Blended-product sales that include any biotech ingredient (fermented or cultivated) were allocated to the respective biotech category—ie, the sale of a plant/cultivated hybrid product is considered "cultivated" for end-product sales. The noticeable drop in plant-based product sales should therefore be seen as driven in significant part by the increase in blended-product sales.

McKinsey & Company

About fermentation and cultivation of cell cultures

Bioreactors are large vessels that create controlled environments to support biological processes. In these vessels, microorganisms such as yeast, bacteria, or cells are fed a carbon source (typically glucose or sucrose) and produce useful chemicals or materials. These materials are then harvested from the broth and used to create products.

In biomass, or whole-mass, fermentation, the microorganisms themselves are harvested and used as proteins. One example is the mycoprotein Quorn, which was brought to market in 1985. A number of companies that use biomass fermentation, such as Nature's Fynd and Superbrewed Food, have launched in recent years.

In precision fermentation, organisms are genetically reprogrammed to produce specific molecules, such as insulin or laundry detergent enzymes. In the food industry, although precision fermentation has been used for decades to make critical proteins such as rennet and other enzymes, it was made famous for alternative-protein applications by Impossible Foods, which launched its heme ingredient in 2016. Precision fermentation is now being used to produce bioidentical versions of other animal proteins, such as whey, collagen, and those found in egg whites.

Cultivation is an analog of fermentation in which cell lines of plants or animals, rather than microorganisms, are used to create useful molecules (such as monoclonal antibodies) or tissues (such as in cultivated meat).[1] In the case of cultivated meat, these cells can be grown on tissue scaffolds to mimic the structure of animal muscles or can be combined with plant proteins and other ingredients to create blended meat-based products.

[1] For more on cultivated meat, see "What is cultivated meat?," McKinsey, September 13, 2023.

To demystify the future of this growing industry, we identified three areas crucial to building and scaling a new food ecosystem:

— *Process improvements and redesigned bioreactors* could drive yield improvements, reduce bioreactor costs, and lower production costs by approximately 50 percent; new bioreactor technology could also expand the global market opportunity for OEMs.

— *Upgraded formulation and food design* could result in a wider variety of high-quality offerings, particularly as companies improve product taste and texture.

— *New business models* could help the industry mitigate risks and finance more than $250 billion in expected infrastructure scale-up.

Production improvements could reduce unit costs by 50 percent

The single most important factor for launching the novel-food market will be reducing the unit costs of novel ingredients. By implementing technological innovations in bioprocessing and downstream production processes—taking a total cost-of-goods-sold (COGS) approach—novel-ingredient companies could have line of sight to cost reductions of approximately 50 percent right now (Exhibit 2).

Most savings are expected to come from primary drivers of the COGS, including titer (the measure of concentration of the desired product in the post-fermentation broth), downstream processing (converting the fermentation broth into a stable product), and cycle time.

Some of these drivers have steadily improved over time. For example, core intellectual property (IP) owners are making continuous titer improvements, and for decades, chemical and pharmaceutical companies have deployed digital analytics and, increasingly, AI to optimize manufacturing.

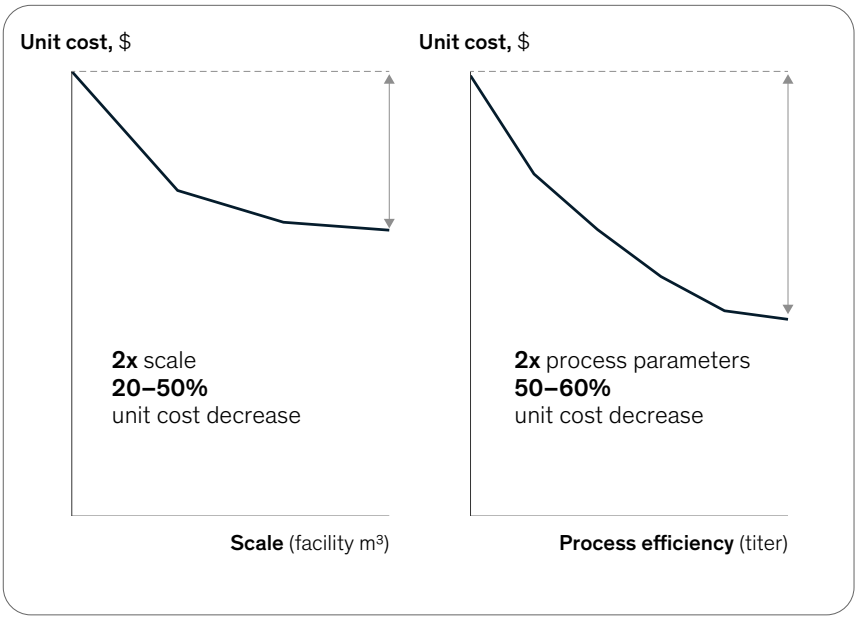
What could truly spur the industry forward is step-change process improvements. More-fundamental changes to bioprocessing could significantly increase active cycle time and capital efficiency. Several start-ups are exploring converting fed-batch processes into continuous ones (see sidebar "Case study: Australian bioprocessing start-up Cauldron"), while other companies are converting traditional aerobic processes into anaerobic ones.

In addition to step-change improvements in processes, it will be critical to upgrade bioreactor technology. Industries such as pharmaceuticals and chemicals have designed fermenters to fit their needs, but bioreactors have not yet been redesigned to suit the needs of the food industry.

Exhibit 2

Process improvements can improve the cost of goods sold for fermented ingredients by up to 50 percent more than scaling alone.

Illustration of unit cost changes: Scaling vs process improvements



Key process optimization levers

- Titer (grams/liter [g/L])
- Recovery yield (%)
- At-spec yield (%)
- Throughput (g/L/hour)
- Operational efficiencies (overall equipment effectiveness)
- Contamination control

McKinsey & Company

New assets must be developed that meet food-grade specifications and move closer to the margin expectations of the food sector.

To get there, bioreactors and their surrounding components need to be stripped down and built from the ground up in a fit-for-purpose way, but global OEMs have yet to address this opportunity. In this gap, some start-ups (including a small set of asset-focused start-ups such as Sterling Bio Machines and Ark Biotech) have redesigned bioreactors and built custom models out of necessity. In addition, some companies are exploring the use of more-modular fermentation tanks to significantly reduce capital costs and drive learning curves.

Better food-formulation capabilities could create groundbreaking new products in the approximately $3.5 trillion protein market

As fermented novel foods begin to come down the cost curve, food and beverage companies will have the chance to introduce new ingredients and offerings for consumers. While precision-fermented ingredients are genetically the same as their animal-derived counterparts, biomass proteins offer unknown and exciting possibilities because many of these ingredients are totally new to human consumption. New tastes, meat alternatives, and beverages will become available, and innovators that have strong food-formulation capabilities will stand out from the pack.

Case study: Australian bioprocessing start-up Cauldron

Cauldron is a precision-fermentation company that has developed and implemented continuous-fermentation methods. We interviewed CEO Michele Stansfield and CFO David Kestenbaum about how they navigate problems and find efficiencies as a start-up in the novel-ingredient space. This interview has been edited for clarity.[1]

McKinsey: Tell us about your continuous-fermentation technology. What problems does this technology let you address?

Cauldron: Historically, running continuous fermentation has been a challenge due to contamination of the ferment and genetic drift of the microorganism population. Our "hyper fermentation" process makes it possible to run our fermentation continuously over multiple weeks. We maintain microorganisms in a productive state, which maximizes output and reduces the amount of "downtime" in the fermentation cycle. We've run our hyper-fermentation process for as long at eight months and 24 days at a scale of 10,000 liters. These productivity gains translate into lower cost of goods sold and better capital efficiency, which have been key roadblocks to the development of the sector.

McKinsey: What challenges do you see for the novel-ingredients supply chain?

Cauldron: One of the most overlooked challenges today is access to adequate levels of feedstock. If you're trying to achieve price parity but spending too much on glucose, then it's tricky to have a competitive price in the market. The other big challenge is access to manufacturing capacity, which can be hard to find.

McKinsey: How are you working to build ecosystems to support your business?

Cauldron: We want to build partnerships that help speed up time to market and make it easier for precision-fermentation companies to go from lab to commercial scale—encouraging specialization and allowing everyone in the industry to focus on what they do best. So far, we have formed partnerships with strain engineering and bioprocessing companies upstream from us and are exploring joint ventures with supply chain partners to scale up our manufacturing capacity.

[1] Comments and opinions expressed by interviewees are their own and do not represent or reflect the opinions, policies, or positions of McKinsey & Company or have its endorsement.

As food scientists learn the true breadth of the texture, taste, and protein fortification capabilities of novel proteins, companies will be able to create unique proprietary offerings for consumers. Manufacturers can experiment with using novel fats, for example, to improve mouthfeel and add savory flavors to food while replacing undesirable ingredients such as palm oil. Precision fermentation could also allow manufacturers to use individual egg, dairy, or other proteins that offer more-specialized nutrition, tastes, or textures. It may be that these novel ingredients can replace many traditionally sourced products such as gums and methylcellulose that deliver critical performance benefits in foods but that can be considered undesirable by consumers.

Knowing what consumers are interested in will be key to driving the development of new foods. As outlined in a recent McKinsey article, consumer insight at this stage is nascent but shows promise for novel ingredients.[5] Depending on the ingredient, 49 to 67 percent of consumers indicated willingness to try food and drinks containing novel ingredients. Survey results also indicated that consumers are particularly interested in trying novel ingredients in snacks and during lunch. These results can provide guidance for food formulators as they develop new offerings and work to educate consumers about novel ingredients.

Scaling the industry poses a investment opportunity to build new business models of more than $250 billion

To drive the expected scale of this industry, $250 billion or more may need to be invested in fermentation assets over the coming 30 years, according to McKinsey analysis. This global expansion approximates the type of industry shift that solar panels and electric vehicles (EVs), for example, have seen in previous years.

The infrastructure investment needed is likely too large to be funded solely by venture capital. And until remaining technology and commercial milestones are achieved, project finance and growth

[5] Kimberly Stover, Kate Toews, and Roberto Uchoa, "Novel proteins: Consumer appetite for sustainably made ingredients," McKinsey, March 21, 2024.

Manufacturers can experiment with using novel fats, for example, to improve mouthfeel and add savory flavors to food while replacing undesirable ingredients such as palm oil. Precision fermentation could also allow manufacturers to use individual egg, dairy, or other proteins that offer more-specialized nutrition, tastes, or textures.

equity players remain reluctant to enter. This leaves a gap in the global funding landscape that the ecosystem can adapt to fill (Exhibit 3).

To unlock new funding models and allow global capital pools to begin investing at scale, two areas need to be addressed:

— *Commercial offtakes* have been the linchpin in securing debt in major capital expansions in other industries, such as EV batteries, sustainable aviation fuel, and hydrogen technologies. In consumer sectors, binding offtakes have traditionally been less common, but start-ups and large food companies are beginning to enter joint development agreements.

— *Technological risks* can deter investors, particularly as process innovations, redesigned bioreactors, and new foods are being tested. However, technological developments regarding process, assets, and scale are expected to deliver material cost reductions over the coming five years, providing a compelling case to investors.

New business models are the key underlying factor that will allow the novel-foods industry to address these points. If start-ups and other players in the novel-food space can build an offtake and risk-sharing ecosystem, they could attract investors and bridge the funding gap. These connections would also make it easier to improve process technology, build better bioreactors, and commercialize novel foods.

A few types of partnerships and funding are already proving to be effective in the novel-foods space:

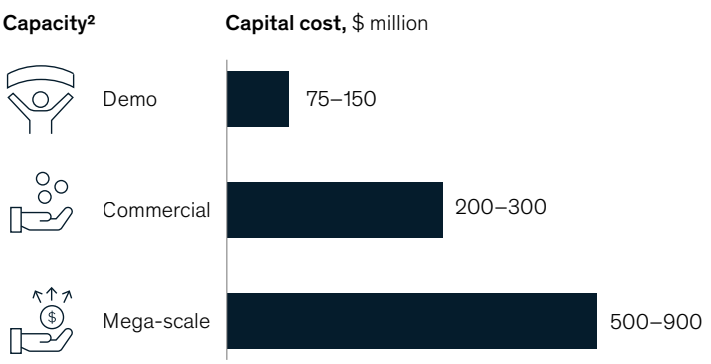
JVs. Joint ventures (JVs) can be used to share risks—and returns—across many players, unlike CMOs, which alter the unit cost structure of a product. Although JVs can be complex, a number of start-ups are exploring these arrangements and other alliances that bring together multiple sources of capital to derisk investment and jointly contribute IP and assets. For example, the Oman Investment Authority has partnered with MycoTechnology to build a facility to upcycle waste dates into mycelium proteins.[6]

[6] "MycoTechnology partners with Oman Investment Authority to target alternative protein opportunity," PR Newswire, May 4, 2022.

Exhibit 3

Significant capital outlay is required for new assets, and many sources of capital can be explored.

Capital expenditure breakdown for greenfield[1] plant employing conventional fed-batch technology



Example capital sources

- Venture financing (20% internal rate of return [IRR])
- Institutional or sovereign wealth funds (10–18% IRR)
- Infrastructure funds (10–15% IRR)
- Strategic or commercial partners (IRR varies)
- Government-supported (eg, grants)

[1]Assumes greenfield construction. Retrofit of an existing facility could save 20–30% in capital expenditures.
[2]Demo has a capacity of 200 kiloliters, commercial has a capacity of 1 megaliter, and mega-scale has a capacity of 10 megaliters.

McKinsey & Company

Sovereign investment. While corporate venture capital has cooled over the past few years, we expect it to rise to previous levels in the long term, given its strong track record in the food industry. In the meantime, sovereign and strategic investment interest remains high. For example, the Dutch National Growth Fund has allocated €60 million for precision fermentation and cultivated novel ingredients.[7]

Government programs. Many countries are creating government programs to support the budding fermentation industry, such as by providing nondilutive funding and facilitating new capacity build-out. For example, in a recent fundraising round, Business Finland, an organization run by the Finnish government, issued Onego Bio a $10 million grant.[8] And Change Foods agreed to concentrate its animal-free dairy production in the United Arab Emirates, supported by the UAE NextGen FDI Initiative.[9]

Considerations for novel-ingredients players launching the industry of tomorrow

The investors, strategic partners, and commercial partners that come together with innovators will be builders of the novel-foods market and will play a crucial role in fueling the global growth of biotechnology. For each group of players, a few factors will be important to consider:

Ingredients incumbents. Biotech-produced foods can allow ingredients manufacturers to expand their portfolios and build a competitive edge through unique formulation capabilities and know-how. Because novel proteins can be produced anywhere, they offer an opportunity for ingredients incumbents around the world to enter animal protein markets for the first time, shifting the competitive landscape for products such as dairy, collagen, eggs, and even non-protein products such as cocoa.

[7] "Netherlands to make biggest ever public investment in cellular agriculture," Good Food Institute Europe, April 14, 2022.
[8] "Onego Bio raises $40M to scale up animal-free egg production," Onego Bio, April 2, 2024.
[9] "Change Foods is making big moves in the UAE," PR Newswire, October 20, 2022.

Find more content like this on the
McKinsey Insights App
Scan • Download • Personalize

OEMs. As the asset base to support biotech-enabled ingredient production is constructed, there is a significant market opportunity for bioreactor and downstream processing OEMs. In the novel-ingredients industry, much of the asset base currently in use is borrowed from other industries and has yet to be value-engineered for food production. The companies that choose to invest in designing and developing fit-for-purpose technology over the coming years may become critical players as global capital expansion continues.

Innovators. Start-ups are eager to bridge volume needs with on-demand capacity, and they stand to benefit greatly from partnerships with incumbent players and investors. In the current macroeconomic funding environment, some players may fail to demonstrate progress fast enough to continue to secure funding, leaving a narrowed field of innovators. Looking forward, each innovator will need to make choices about what capabilities to invest in, from titer improvements to ongoing IP creation. Developing food formulation capabilities and a distinctive understanding of how to work with novel ingredients could offer a competitive edge as more proteins are commercialized.

Investors. As stakeholders mature, traditional investors are increasingly exploring the sector and looking into business models that might allow for greater investment. Establishing infrastructure-grade financing from securitized assets with committed offtake at market-clearing prices is expected to be critical for scaling the industry, as in other industry scale-ups such as wind and solar.

Over the coming five years, we expect a combination of cost parity and consumer demand to mature and derisk the novel-ingredients industry, leading to a global infrastructure expansion. In the meantime, leaders can continue building creative mechanisms to balance capital, risk, and returns. If players can enter this investment opportunity now, they have a chance to build the food supply chain of the future.

Daniel Aminetzah is a senior partner in McKinsey's New York office, **John Levene** is a partner in the New Jersey office, **Tom Brennan** is a partner in the Philadelphia office, and **Kate Toews** is an associate partner in the Chicago office.

The authors wish to thank Bryan Vadheim, Jannik Buddenberg, and Olivia Sánchez Badini for their contributions to this article.

Copyright © 2025 McKinsey & Company. All rights reserved.