Good Food Institute

ACTION PAPER

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Manufacturing capacity landscape and scaling strategies for fermentation-derived protein

A summary of recommended industry stakeholder actions

A report by the Good Food Institute and Integration Consulting takes a census of existing global fermentation-based alternative protein production capacity, assesses the decision points for determining whether to contract manufacture or self-produce, and explores salient considerations for developing fermentation facilities for the alternative protein industry. This summary highlights key insights from the analysis and outlines recommended actions for industry stakeholders.

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Overview

The range of fermentation-derived alternative protein products has expanded tremendously in the past several years. New offerings include iron-binding proteins for plant-based meats, whey proteins for animal-free dairy products, and fungal whole-cell protein for breakfast sausages. Driven by innovations in biotechnology that enable microbes like yeast and bacteria to produce proteins, fats, and other ingredients, many foods can now be made using animal-free methods. Furthermore, the biomass fermentation industry has seen a rapid diversification in microbial species, production methods, and consumer products. Together, these advancements have set the stage for fermentation-derived products to earn widespread presence in food formulations and on store shelves.

More and larger fermentation facilities suitable for food production are needed to accommodate rising demand and ever-improving innovations in microbial biotechnology and fermentation approaches. Scaling up production to achieve lower price points is also needed to support increased demand in the coming years.

The Good Food Institute and Integration Consulting have authored a report, summarized in this document, to identify the volume and capabilities of existing global fermentation facilities able to produce alternative proteins and food ingredients. This capacity is characterized by scale, geographic region, and availability for contract manufacturing. The report also explores the trade-offs of strategies to scale manufacturing capacity, including partnering with contract manufacturing organizations (CMOs), building greenfield sites, or retrofitting brownfield facilities and equipment as informed by expert interviews and an industry survey.

This report covers key considerations for each scaling strategy across six major decision factors—overall cost, value chain connectivity, lead times, intellectual property protection, financing, and access to a talented workforce. Further, this report identifies limitations of existing capacity and recommends strategies for scaling that serve a range of industry players and promote overall category growth.

Fermentation is a well-established platform for producing products like beverages, industrial enzymes, and fuels because humans have domesticated microbes for thousands of years and industrialized many fermentation-derived products over the past century. The report also includes an overview of available opportunities to retrofit existing fermentation facilities in parallel industries to produce alternative proteins, fats, or novel ingredients. We analyze facility types available for retrofit, their corresponding markets, and the appropriateness of the equipment they contain.

Click here for the full report: Manufacturing capacity landscape and scaling strategies for fermentation-derived protein

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Key findings

There are 16 million liters of fermentation capacity available to the fermentation-derived food protein industry across the globe.

A known 89 companies provide 16 million liters of food-certified fermentation capacity and associated process equipment to the alternative protein industry. These companies are capable of producing 0.4 million tonnes of alternative protein products per year. When all potential contract manufacturing capacity from the pharmaceutical and bioindustrial sectors were included, this number rises to 2.8 million tonnes of alternative protein product. The majority (81 percent) of the identified capacity across all production scales is in North America (34 percent) and Europe (47 percent)[1].

An increase in the number of fermentation-derived protein products, offtake agreements, and consumer demand will stress the current fermentation capacity. Strategic scale-up of fermentation capacity with associated increases in biological and bioprocess efficiency will be required to meet demand.

Current fermentation capabilities do not meet the needs of development projects for new protein/products.

To optimize production, new fermentation processes must be scaled from lab to demonstration to commercial processes. Many current fermentation-derived protein companies require piloting support to make their products commercial-ready. There is a notable scarcity of these pilot and demonstration scale facilities that can develop and certify a process for commercial-scale production. These smaller-scale facilities, whether at research institutions or contract development and manufacturing organizations (CDMOs), play a vital role in bringing bioproducts from lab through to commercial scale by shortening lead times and lowering up-front capital investment compared to constructing a company-held facility.

Today, fermentation capacity is roughly split between proprietary fermentation capacity and food-exclusive CMOs. Institutional pilot/demonstration facilities and CMOs play an important role in supporting the ecosystem by providing bioprocess experience and guidance on process development.

Developing and building a fermentation facility for alternative proteins is highly context-specific.

Start-ups favor pathways that allow them to invest in less capital-intensive strategies due to their resource constraints and risks associated with the early development of technology and products. These companies look to leverage CMOs for their existing infrastructure and bioprocess experience.

At a commercial scale, companies with more mature technology and demonstrated processes are more likely to build their own fermentation facilities to achieve greater operational control and process efficiency. The time and developmental roadmap to committing to an owned facility varies by product type and manufacturing method.

For example, biomass fermentation approaches generally have a less complex downstream processing compared to precision fermentation. These companies may decide to construct their own facilities earlier in their commercialization process. On the other hand, the complexities of precision fermentation may lead these companies to rely on CMO support further into the commercialization process.

Opportunities to retrofit facilities and equipment exist in commercial fermentation for ethanol production.

Fermentation for ethanol production—whether for beer, biofuel, or wine—utilizes standard equipment and relatively simple downstream processing. It also

[1]Note that this analysis did not examine capacity devoted to fermentation-derived animal feed products due to the regulatory framework and standards differences between food and feed production.

has low margins and slower industry growth than other parallel fermentation industries such as pharmaceuticals and enzyme production. As a result, there are potential opportunities within the beer, wine, and biofuel industries for retrofitting. These facilities are located near fermentation value chains, provide proper utility (power, water, wastewater) access, and are right-sized structures. However, much of the equipment at these facilities would require significant modification and optimization to be suited for most fermentation-derived protein manufacturing, especially considering the anaerobic nature of ethanol fermentation. If the proper resources were dedicated to developing retrofit hardware and identifying microbes well-suited for anaerobic or semi-aerobic reactor vessels, additional existing fermentation facilities and equipment could be co-opted for retrofitting.

Generally, retrofitting equipment becomes less attractive as companies scale their production capacity. Currently, the nature of these equipment retrofits typically requires a compromise in process efficiency as compared to fit-for-purpose equipment. This tradeoff becomes a larger penalty as companies increase production volume.

Key industry recommendations

Producers of fermentation-derived alternative proteins:

Maximize the output of existing capacity with improved strains and bioprocesses.

Existing fermentation capacity can potentially produce more tonnage of product than the current output. Increasing the biological production capacity of fermentation microbes could increase the output from existing fermentation capacity and increase the product titers from future fermentation facilities. Some precision fermentation organisms, like filamentous fungi, may be capable of producing nearly 100 g/L of native proteins, compared to current industry averages of <50 g/L. While it may not be possible to recapitulate this performance with recombinant protein production, continuous improvement on current capabilities can lower the capital expenditures (Capex) required to achieve certain production volumes. In biomass fermentation, process optimization should maximize cell densities and growth rates to increase the amount of biomass that can be generated per fermentation volume per year. In all fermentation-derived protein bioprocesses, especially downstream processes, producers should focus on reducing product cost and maximizing processing material recovery while minimizing or valorizing costly waste streams.

Utilize/consider contract development and manufacturing organizations in early stages of process development and product commercialization.

Fermentation-derived producers have "capital light" pathways to scale-up and commercialization. Institutional and private pilot facilities are an important step for bringing an alternative protein product to market. For companies focusing on a few products with long R&D cycles, developing in-house pilot and demonstration scales is an expensive proposition with infrequent ROI. Instead, these companies should rely on external lab, pilot, demonstration, and early commercial facilities to scale up an effective and volumetric bioprocess. For these and many other scenarios, institutional or private CDMOs/CMOs can offer institutional knowledge and an experienced workforce.

Recognize that, industry-wide, different pathways to manufacturing capacity will lead to different outcomes.

New-build construction and facility retrofitting have a general trade-off between lead time and production efficiency. Manufacturers (or future CMOs) working toward operational facilities can often achieve a shorter lead time to commissioning if they choose to retrofit an existing facility. However, based on the original purpose of these facilities and resulting design idiosyncrasies, achieving process efficiency that approaches a new-build facility with a fit-for-purpose design may be challenging. Some fermentation bioprocesses, such as biomass fermentation, are more amenable to retrofitting. Hybrid approaches including retrofitting a portion of a larger facility and associated equipment and allocating space for future bioprocessing lines may allow for faster facility development while planning for enhanced bioprocess efficiency with later additions.

Investors:

Develop funding structures to support larger-scale capital projects and infrastructure needs.

Industry success depends on startups and biotech companies securing funding for capital expenses and large-scale infrastructure. Current funding structures may not meet the needs of companies scaling up manufacturing capacity. Both funders and companies need to innovate in this space to derisk investments. Interviews with industry experts indicate that derisking capital investment is key to creating a compelling target for funders. Creative approaches include:

- Diversifying and modularizing facilities to make them fit for purpose, while allowing for time- and cost-efficient turnover of companies and production of other biomanufacturing products in addition to alternative proteins.
- Leveraging partnerships with existing players in fermentation or food production.
- Joining or forming coalitions in which smaller companies can share resources and value chain positions where possible.

If such investment were adequately derisked, non-dilutive financing solutions, including project financing and debt, could be leveraged as efficient and fit-for-purpose scale-up financing. In addition to the suggestions noted above, standard derisking mechanisms such as offtake agreements would be effective. Further, investors with interests that are not purely financial, including strategic or sustainability mandates, may be able to bear higher financial risk to meet their goals.

Early successes in manufacturing investment will help guide future opportunities in fermentation scale-up.

Equipment manufacturers:

Create hardware that addresses retrofit opportunities.

Retrofit conversion technologies could help fermentation facilities scale quickly. For example, anaerobic fermentation facilities like those used for ethanol production could become available for fermentation-derived protein production. Such a conversion would change the technoeconomics of the facility but would demand an extensive overhaul. Focusing on the conversion of one or more types of anaerobic fermenters (beer, wine, biofuel) to mixed/circulated fermenters with improved aeration, feeding, and environmental control, would enable upstream bioprocessing in formerly unsuitable vessels.

Improve downstream process recovery or Capex.

Properly aligned downstream processing equipment would lower costs and maximize product recovery for fermentation-derived alternative protein. In biotechnology for fermentation, many of the downstream processing approaches are cost intensive. Some of these processes are borrowed from the pharmaceutical industry which requires a higher product purity than the food industry requires. Other industrial separation and purification technologies and equipment come from industrial chemical fermentation where liquid handling for the commodity scale is achieved but at a considerable loss of product or lower purity. Equipment manufacturers should look to establish an array of distinct food-grade fermentation ingredient separation technologies that focus on meeting the end-product purity and volume requirements distinct to the food industry.

Contract manufacturing organizations:

Market your fermentation capacity and capabilities widely for better awareness by customers, policymakers, and the value chain.

Globally, CMOs are difficult to identify and characterize, but CMOs can quickly increase their visibility to potential clients and others in the ecosystem. The flurry of R&D and startup activity in fermentation-derived alternative proteins is generating a pipeline of new companies looking to develop and commercialize novel products and bioprocesses. Often, identifying supporting CMOs/CDMOs is a difficult task, made easier by contract facilities self-identifying their capacity and capabilities in global and regional databases such as Capacitor.bio, BioP2P, or Pilots4U. A census of fermentation capacity by location would help to drive assessments by policymakers to ensure that there are no capacity stages overlooked by public biomanufacturing support. Further, identifying loci of fermentation capacity would help feedstock suppliers, and warehouse, logistics, and equipment companies streamline support to the industry.

Increase client confidence in intellectual property protection.

Novel organisms, fermentation conditions, and bioprocess steps are key aspects of many fermentation-derived protein producer portfolios, and intellectual property (IP) sensitivity is a hurdle to some fermentation-derived protein producers. Many other biomanufacturing processes occur using relatively standardized microbes, processes, and feedstocks. Alternative protein production utilizes specialized steps and bespoke microbes that define the value proposition of the client companies, making it more comparable to the pharmaceutical industry. Increasing client confidence by adopting some of the methods for IP protection from pharmaceutical CMOs may unlock new client bases previously apprehensive about contract manufacturing.

About the author

Adam is a lead scientist in fermentation at GFI and is focused on the development of biomass fermentation and precision fermentation biotechnology for food protein. He earned a BS in molecular genetics from the University of Rochester and a PhD from Drexel University College of Medicine in molecular biology. Adam's postdoctoral studies concentrated on fungal genetics and systems biology. During his time in biotech, Adam implemented gene expression analyses in microbial, agtech, and human health studies to better characterize these systems and offer a deeper understanding of strain development and process improvement.

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About GFI

The Good Food Institute is a 501(c)(3) nonprofit working internationally to make alternative proteins like plant-based and cultivated meat delicious, affordable, and accessible. GFI advances open-access research, mobilizes resources and talent, and empowers partners across the food system to create a sustainable, secure, and just protein supply.

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