Manufacturing capacity landscape and scaling strategies for fermentation-derived protein

Good Food Institute.
Integration

Executive Summary

Fermentation-derived products are a rapidly growing category within alternative proteins. Driven by innovations in biotechnology that enable microbes like yeast and bacteria to produce proteins, fats/oils, 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. To ensure long-term category growth, the industry must identify and address limitations in manufacturing capacity and technical capabilities to accommodate rising demand and ever-improving innovations in microbial biotechnology and fermentation approaches.[1]

This report supports industry decision-making by capturing the global manufacturing capacity landscape of fermentation-derived products and exploring the trade-offs of strategies to scale manufacturing capacity, including partnering with contract manufacturing organizations (CMOs), constructing greenfield and brownfield[2] sites, and retrofitting[3] used equipment. Additionally, this report combines data analysis, industry-wide insights, and viewpoints from a diverse range of players across the fermentation-derived product value chain to provide an overview of challenges facing these product manufacturers along with valuable considerations for how to address them.

When mapping the fermentation-manufacturing landscape using available databases and desk research, we estimated that the global fermentation-derived product manufacturing capacity is approximately 16 million liters, split between 48 known producers (business-to-consumer or business-to-business companies) with their own in-house manufacturing capabilities and 41 food-exclusive CMOs. Capacity is predominantly concentrated in Europe (47%) and the U.S. (34%), with a notable lack of dedicated food-grade commercial manufacturing facilities in Africa, Latin America, and Asia Pacific.

Across the industry, CMOs play a key role in accelerating the industry. This is especially true for early-stage companies working with precision or liquid-biomass fermentation. CMOs offer the benefit of requiring capital-light investments, thereby granting companies easier access to financing while also leveraging external skills and expertise that they may lack internally. When seeking to achieve commercial scale, companies tend to partner with CMOs until the higher operating costs of contracted services make it more economically advantageous to build proprietary production facilities. However, the limited availability of CMOs across all stages of development remains a challenge, especially for early-stage companies planning or setting up viable operations.

Global fermentation-derived product manufacturing capacity is approximately 16 million liters, split between 48 known producers (business-to-consumer or business-to-business companies) with their own in-house manufacturing capabilities and 41 food-exclusive CMOs.

Where technically feasible, brownfield development and retrofitting equipment have the potential to significantly reduce up-front capital expenditure (CAPEX) by more than 70 percent and shorten construction lead times to six months. However, with no blueprints available for how to retrofit the equipment involved (particularly fermenters), possessing the necessary skills and expertise in-house is a critical factor for making a retrofit viable long-term.

> *Brownfield development and retrofitting equipment have the potential to significantly reduce up-front capital expenditure (CAPEX) by more than 70 percent and shorten construction lead times to six months.*

We identified several parallel industries with facilities that could be suitable candidates for retrofitting.

Among the seven industries identified, three present the most potential for converting or retrofitting capacity:

Beer breweries:

Significant process similarities and advantageous market conditions indicate the availability of idle or decommissioned facilities and equipment.

Ethanol plants:

Co-location with corn milling provides direct access to the cheapest source of feedstock needed for fermentation, thereby reducing supply chain risk and operating costs.

Wineries:

A potential business case exists for leveraging 75 percent of equipment downtime throughout the year related to the seasonality of wine production, especially compelling for U.S. wineries which generally use stainless-steel (and therefore sterilizable) fermenters.

To fully capitalize on the market potential of fermentation-derived products, beyond volumetric capacity, organizations will need to develop the supply capabilities within this category. In the short term, companies should direct investments toward developing lab- and demo-scale CMO capacity to help early-stage companies reach commercial-scale production. In the medium term, as fermentation technology matures and more companies reach commercial production scale, the focus should shift to developing commercial-scale capacity that caters to fermentation needs for producing alternative protein-based food products.

Introduction

The category of biomass and precision fermentation-derived cells, proteins, and other ingredients for use in human food products (collectively referred to as fermentation-derived products in this report) is rapidly evolving and has significant growth potential. While some companies have been manufacturing fermentation-based products for over three decades, such as Quorn's fungus-derived mycoprotein, recent technological advancements, especially in precision fermentation, have the potential to enhance alternative protein products' nutritional value, taste, and texture, which are among the main barriers to consumer adoption.

While the fermentation-derived products category is still in its early stages, it has experienced significant investment and growth in a short time. From 2013 to 2022, the average global investment in fermentation-derived products tripled, and the number of product companies increased from 7 to 136.[4] There has also been a surge in companies and investment dedicated to researching and developing innovative solutions to further improve the taste, functionality, and production efficiency of fermentation-derived products.

As companies direct more investment toward the technological advancement of fermentation-derived products, access to manufacturing capacity and the technical capabilities required at different technology development stages and production scales (particularly for precision fermentation) has become a bottleneck for further growth. Players across the industry have recently made efforts to address this bottleneck. For example, the Capacitor and Pilots4U databases show available manufacturing resources at all scales and companies, like Liberation Labs and Planetary, to help develop contracted, commercial-scale manufacturing facilities dedicated to fermentation-derived product production.

With the aim of supporting efforts to overcome manufacturing capacity and capability barriers, this report provides greater clarity on the current global manufacturing landscape of fermentation-derived products and explores the advantages and disadvantages of different strategies to scale up capacity, from the use of contract manufacturing organizations (CMOs) to developing existing brownfield manufacturing sites and retrofitting used equipment.

This report combines data analysis, industry-wide insights, and viewpoints from a diverse range of players across the fermentation-derived product value chain to provide insights into the challenges facing fermentation-derived product manufacturing along with valuable considerations for how to address them.

Authors

About The Good Food Institute

The Good Food Institute is an international nonprofit building a sustainable, healthy, and truly global food system. With unique insight across the scientific, policy, industry, and investment landscapes, we are using the power of food innovation and markets to accelerate the transition of the world's food system toward alternative proteins. GFI is powered by philanthropy, and all of the resources we produce and analyses we conduct or commission are intended to be shared in an open-access manner to focus efforts on the highest-impact opportunities.

About Integration

Integration is a global strategy and management consultancy with over 25 years of experience guiding clients from diverse industries through complex transformations for which there are no tried-and-tested paths to success. Our recent work across different parts of the food system value chain has recently included:

- Supporting plant-based meat companies in bringing their products to new markets.
- Designing circular economy models for packaging companies to reduce waste.
- Creating a disruptive roadmap for a cultured meat client to win in selected markets globally.

Project Team

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Design and Scope

Report design

We have divided this report into two main sections based on the analysis and report framework in Figure 1.

Section 1 / Fermentation-derived product capacity landscape: This section provides an overview of the fermentation-derived product manufacturing landscape including the quantity and distribution of fermentation capacity across production scale and geography.

Section 2 / Strategies to scale fermentation-derived product manufacturing capacity: This section defines different strategies for fermentation-derived product companies to scale manufacturing capacity and capabilities and criteria for evaluating each strategy, expands on the trade-offs between the different strategies based on in-depth industry interviews and desktop research, and evaluates the potential of several parallel industries for retrofitting for fermentation-derived product production.

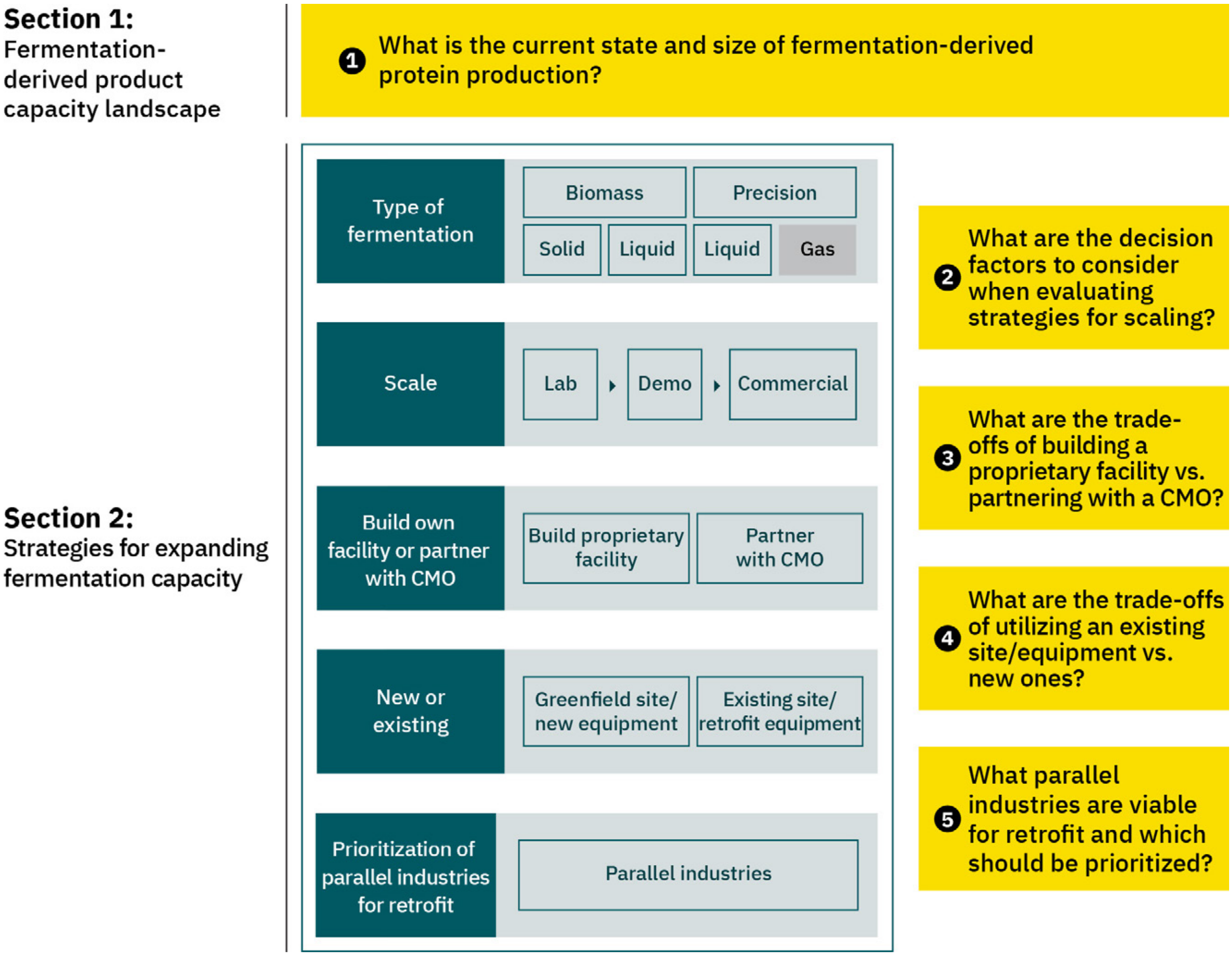


Figure 1. Analysis and report framework

Scope

This report focuses on manufacturing capacity for producing fermentation-derived protein products for human consumption, specifically animal-free meat, egg, and dairy products, including:

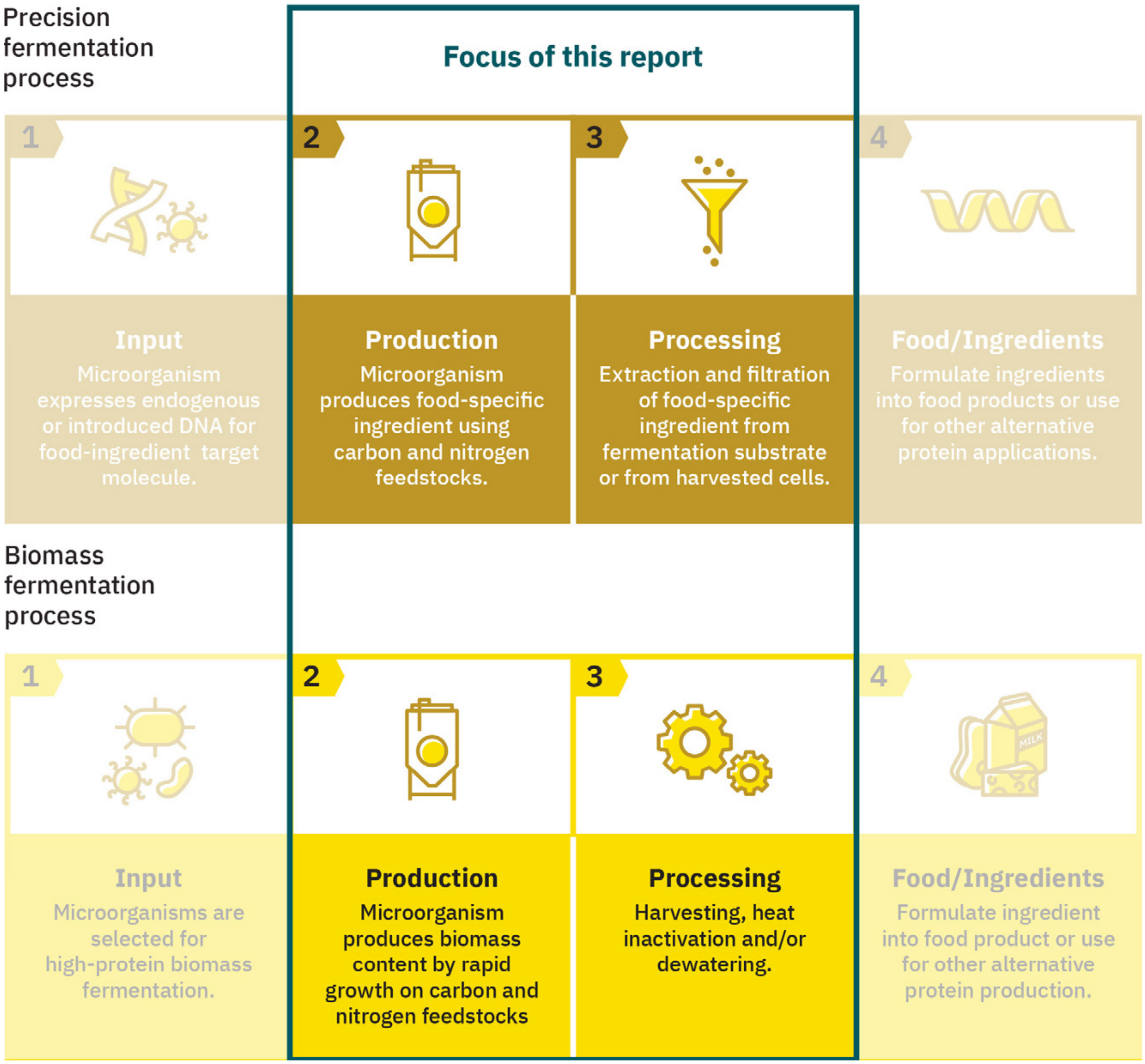
- Microbes (such as bacteria, microalgae, and single-cell fungi) used to produce edible biomass or functional ingredients for animal-free meat, eggs, and dairy, as well as functional ingredients for cultivated meat production (such as cell growth factors).
- Mycelium to produce edible biomass or functional ingredients for animal-free meat, eggs, and dairy.

This report includes input and data from around the globe, however, there is a particular focus on the U.S. and Europe due to limited data availability from outside of these regions.

The report does not discuss the capacity to produce fermentation-derived products for uses beyond animal-free meat, egg, and dairy products, such as:

- Fermentation to produce food items other than those for human consumption (enzymes and processing aids).
- Fermentation to produce molecules for non-food applications (such as biofertilizer, farmed animal feed, aquaculture feed, chemicals, biofuel, cosmetics, and biologics).
- Nut-based and other fermented cheese and butter made from plants.
- Tempeh and other traditional fermented foods such as sourdough or kimchi that are not analogous to meat, egg, or dairy products.
- Mushrooms (fruiting bodies of some fungi).
- Macroalgae (such as kelp, seaweed, dulse, and sea vegetables).

We define biomass and precision fermentation processes through four steps: input, production, processing, and food/ingredient post-processing. This report and analysis focus on the capacity required for the production and processing steps (Figure 2).



Precision fermentation process

Focus of this report

1 Input
Microorganism expresses endogenous or introduced DNA for food-ingredient target molecule.

2 Production
Microorganism produces food-specific ingredient using carbon and nitrogen feedstocks.

3 Processing
Extraction and filtration of food-specific ingredient from fermentation substrate or from harvested cells.

4 Food/Ingredients
Formulate ingredients into food products or use for other alternative protein applications.

Biomass fermentation process

1 Input
Microorganisms are selected for high-protein biomass fermentation.

2 Production
Microorganism produces biomass content by rapid growth on carbon and nitrogen feedstocks

3 Processing
Harvesting, heat inactivation and/or dewatering.

4 Food/Ingredients
Formulate ingredient into food product or use for other alternative protein production.

Figure 2. Fermentation in the alt protein industry

Definitions

Fermentation type

While fermentation covers a broad range of biological processes, we focus on biomass and precision fermentation in this report and in the context of fermentation-derived products. Liquid-state fermentation is considered within both. Due to current offerings, this analysis only considers solid-state fermentation within biomass.

Despite the processes involved being broadly similar, the steps and equipment used in each can be different. The process maps pictured in Figure 3 outline the primary steps and equipment in the biomass and precision fermentation production process.

Scale

This report uses specific terms to describe the sizes and stages of development of fermentation-derived product companies e.g., start-up, early-stage, lab, scale-up, growth-stage, bench, pilot, demo, commercial, and industrial. This report defines lab, demonstration (hereafter demo), and commercial scale, as shown in Figure 3.

Development

Section 2.2 evaluates different build-out strategies for developing manufacturing capacity in terms of the previous use (or lack thereof) of sites and equipment. Definitions of greenfield, buy new, brownfield, and retrofitting pathways are shown in Figure 4.

Contract manufacturing organizations

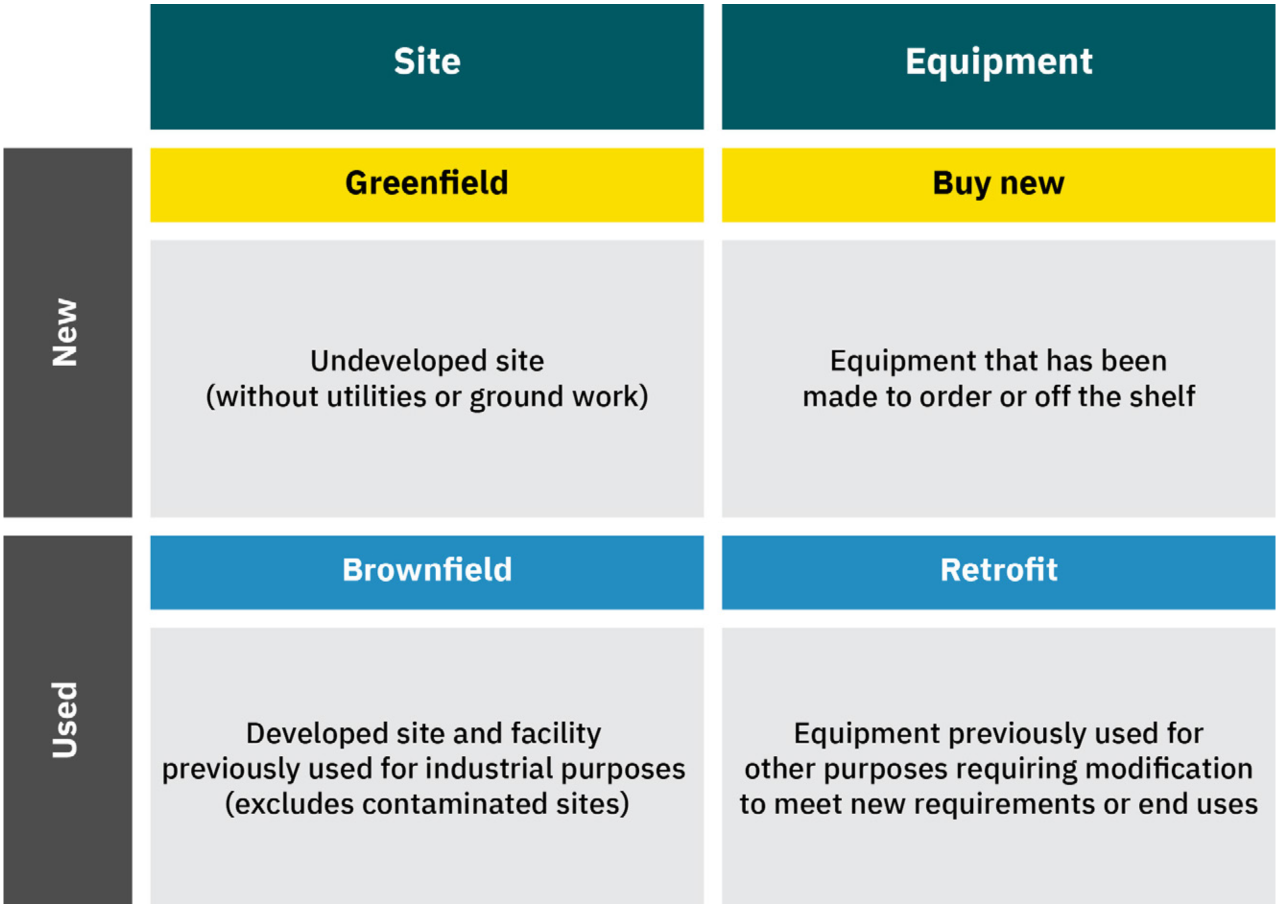
While the terms contract manufacturing organization (CMOs) and contract development and manufacturing organizations are often used interchangeably, this report uses the term CMO to refer to any third-party manufacturing company.

	Lab	**Demo**	**Commercial**
Size *(fermentation capacity)*	Less than 1 K liters	1–100 K liters	100 K+ liters
Definition	Small-scale setup focused on R&D of process and product feasibility	Larger setup designed to demonstrate the feasibility and scalability of a fermentation process	Large-scale setup designed to produce a commercial quantity of a product
Focus areas	• Strain development • Microbiology • Fermentation optimization	• Offtake agreements with retailers • Downstream process engineering • Formulation optimization • Food science expertise	• Multiple vessel fermentation • Continuous manufacturing • Project management • Resource optimization

Figure 3. Definitions of scales used in this report

Process step *Equipment*	**Biomass** Solid	**Biomass** Liquid	**Precision** Liquid
Obtain pure culture *Culture container*	✓	✓	✓
Inoculate starter *Vessel*	✓	✓	✓
Seed fermenter *Bioreactor (smaller)*	✓	✓	✓
Production *Bioreactor*	✓ Tray system	✓	✓
Heat treatment/ nucleic acid removal *Heating element*	✓ 65ºC	↓	↓
Dewatering/clarification *Centrifuge*	✓	✓	✓
pH adjustment/filtration *Filtration system*	✓	✓	✓
Concentration & diafiltration *Culture container*	↓	↓	✓
Drying/ingredient storage *Spray dryer lyophilizer*	✓ ↑	✓	✓
Process to a meat analog *Frozen, refrigerated, processed*	or ↓ ✓		

Figure 4. Representative fermentation process steps and equipment



	Site	Equipment
New	**Greenfield** Undeveloped site (without utilities or ground work)	**Buy new** Equipment that has been made to order or off the shelf
Used	**Brownfield** Developed site and facility previously used for industrial purposes (excludes contaminated sites)	**Retrofit** Equipment previously used for other purposes requiring modification to meet new requirements or end uses

Figure 5. Definitions of build-out strategies used in this report

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Fermentation-Derived Product Manufacturing Capacity Landscape

Overview

As largely nascent industries, biomass and precision fermentation-derived product companies require access to capacity across all scales to enable efficient expansion and overcome bottlenecks. To connect companies to the facilities and capabilities they need to scale from lab to commercial production, players in the industry have recently begun to compile fermentation manufacturing company and capacity information in publicly available databases.

This section provides insights into the global manufacturing capacity (as of 2022) for fermentation-derived products based on consolidation and analysis of publicly available databases (see Methods section for additional details). Specifically, this section focuses on business-to-consumer (B2C) and business-to-business (B2B) producers and food-focused CMOs to provide an overview of the composition of producers, global fermentation capacity, and potential manufacturing capacity challenges.

Summary of key findings

① Manufacturing landscape of fermentation-derived product producers

- **Number of companies:** There are 102 identified B2C and B2B producers (excluding CMOs) that currently manufacture fermentation-derived products using in-house and outsourced capacity.
- **Company focus (B2C vs. B2B):** 79% of these are either pure-play B2B or B2B/B2C mixed, which is expected as precision fermentation products are primarily used as ingredients.
- **Scale:** The production scale utilized by producers follows a pyramidal distribution, with 46% at the lab, 33% at demo, and 21% at commercial scale.
- **Outsourced vs. in-house:** 23% of companies at lab scale have in-house (owned) fermentation capacity, while 86% of producers at commercial scale have capacity in-house.

② Global capacity to manufacture fermentation-derived products

- **Number of manufacturers**: 89 in-house producers and food-exclusive CMOs.
- **Fermenter capacity**: Existing capacity for fermentation-derived products is approximately 16 million liters.
- **CMOs vs. proprietary**: Capacity is split roughly 50/50 between producers with in-house manufacturing capabilities (7.5 million liters) and food-exclusive CMOs (8.2 million liters).
- **Scale:** Concentrated at the commercial scale, with 82% of total capacity.
- **Geographic distribution:** Concentrated in Europe (47%) and N. America (34%). Mexico, Singapore, and South Korea have the most capacity outside of N. America and Europe.
- **Annual output:** When converted to an annual output, current fermenter capacity could produce between 0.4–2.8 million metric tons of alternative protein product.

③ Challenges of manufacturing fermentation-derived products

- There is a notable lack of capacity outside of Europe and N. America, particularly at a commercial scale.
- Despite having a high level of biotechnological advancement, there is a need to further develop manufacturing capabilities, particularly at the demo and commercial scales, in N. America.
- Limited availability of pilot and demo scale facilities is likely to impact the future growth of the fermentation-derived products category. Specifically, companies require support to cross the valley of death from product development to commercialization.

Overall, developing the category's manufacturing capabilities will be essential to meet growing demand over the next decade as fermentation-derived protein products achieve greater taste and price parity.

Global manufacturing landscape of fermentation-derived product producers

Existing fermentation capacity databases such as Capacitor and Pilots4U focus on CMOs, so less information is available about the manufacturing capacity outsourced or owned and operated by fermentation-derived product producers (B2C and B2B companies, e.g., Quorn). This section provides an overview of the manufacturing landscape of non-CMO producers by consolidating multiple lists[5] of alternative protein-focused companies combined with extensive desk research on individual companies.

We identified 102 producers that manufacture fermentation-derived products, with a mixture of scales and customer focus, as shown in Figures 6 and 7. Only 21 percent of producers pursue an exclusively B2C customer focus, which is expected as many precision fermentation outputs serve as ingredients for consumer end-products manufactured by other companies.

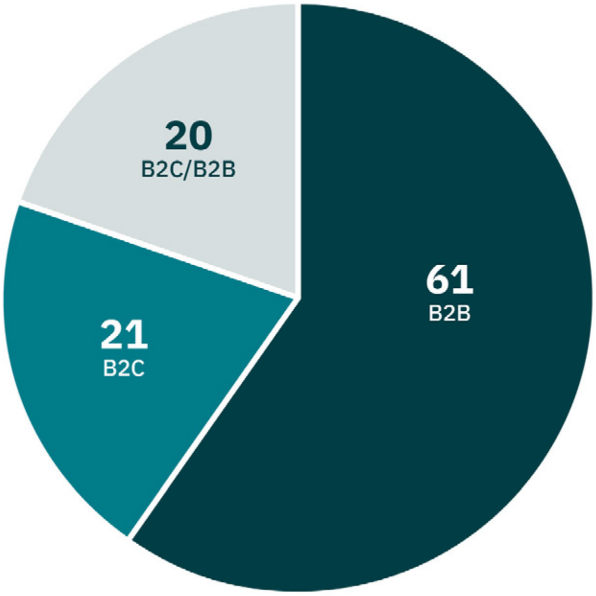
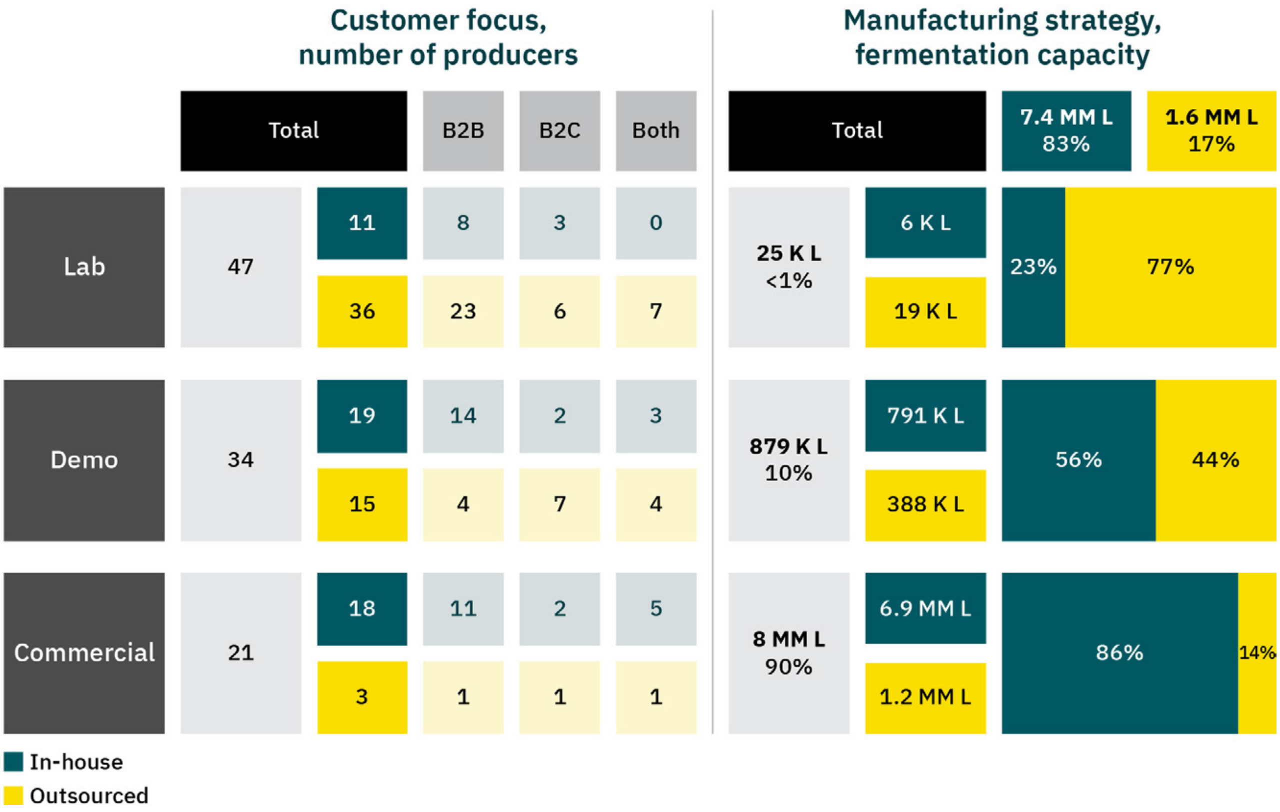


Figure 6. Producers by customer focus

Figure 7. Producers by production scale

Split by scale, these producers exhibit a pyramidal distribution that is typical to development in a new category, with 46 percent of companies at lab scale compared to 21 percent at commercial scale.

Our estimates of both in-house and outsourced capacity volume (Figure 8) show that, as expected, most producers concentrate their fermentation capacity in commercial facilities, accounting for 90 percent of the total utilized capacity by volume. Notably, our analysis reveals that companies are more likely to have in-house manufacturing capacity when at or near commercial-scale fermentation output. At lab scale, approximately a quarter of producers (11 out of 47) have in-house fermentation capabilities, compared to 18 out of 21 producers with in-house capacity at commercial scale. As discussed in more detail in Section 2, primary and secondary research indicates that resource constraints and the uncertainty of technological outcomes and returns on investment complicate the establishment of in-house production capabilities at lab scale. Additionally, the opportunity to utilize university facilities significantly reduces the barriers to initiating lab-scale development. At demo scale, the split is more even, with 56 percent of utilized capacity in-house compared to 44 percent outsourced. A total of 48 producers currently own and operate their own manufacturing facilities (hereafter referred to as in-house producers).



Customer focus, number of producers

	Total		B2B	B2C	Both
Lab	47	11	8	3	0
		36	23	6	7
Demo	34	19	14	2	3
		15	4	7	4
Commercial	21	18	11	2	5
		3	1	1	1

Manufacturing strategy, fermentation capacity

	Total		7.4 MM L 83%	1.6 MM L 17%
Lab	25 K L <1%	6 K L	23%	77%
		19 K L		
Demo	879 K L 10%	791 K L	56%	44%
		388 K L		
Commercial	8 MM L 90%	6.9 MM L	86%	14%
		1.2 MM L		

■ In-house
🟨 Outsourced

Figure 8. Number and fermentation capacity of producers by scale and customer focus

Geographic distribution of producers

Many fermentation-derived producers identified in this analysis are in N. America and Europe (Figure 9), particularly those producing at commercial scale. This uneven distribution is less marked at lab and demo scale, potentially highlighting an overall lack of commercial-scale capacity in these regions. However, it is important to note that access to company and capacity data for regions outside of N. America and Europe is limited, thus the data presented in this section may not capture all existing capacity in Latin America, APAC, Africa, and Middle East regions. Therefore, the data presented may potentially underestimate the global presence and total capacity of fermentation-derived product producers.

Estimate of total global manufacturing capacity for fermentation-derived products

Calculating global manufacturing capacity specifically for fermentation-derived products is challenging because it requires not only identifying existing manufacturing facilities but also the scale of their fermentation capacity and their product portfolio (i.e., food standard, pharmaceutical, and industrial). For this analysis, we compiled this information using publicly available databases supplemented with industry interviews and surveys and extensive desktop research. This section summarizes the number and distribution of identified facilities with the potential to manufacture fermentation-derived products and their production scales, and an estimate of the total global manufacturing capacity based on this information.

Figure 9. Geographic distribution of fermentation-derived product producers by scale and manufacturing strategy (i.e., in-house vs. outsourced)

Number of facilities:

We identified 89 fermentation-derived product manufacturers, of these:

48 are producers with in-house manufacturing capabilities (as described in the previous section).

41 are food-exclusive CMOs (those classified as food standard, not pharma or industrial).

Production scale:

Manufacturers vary in scale as defined by the size of fermenters within their facilities, with common scale classifications being lab, demo, and commercial. Figure 10 shows the average fermentation capacity of each classification for producers with in-house manufacturing capabilities. As shown, the average capacity per company is 15 times greater at commercial scale than at demo scale, and 452 times larger than at lab scale.

Pharmaceutical:

These CMOs produce pharmaceutical-grade products that meet strict regulatory requirements and quality standards. Companies use these products as active pharmaceutical ingredients or as raw materials for medicines, vaccines, and other healthcare products.

Industrials:

These CMOs produce a wide range of products including enzymes, chemicals, and biofuels. Companies typically use these products in industrial processes and applications, such as for bio-based materials or biofuels.

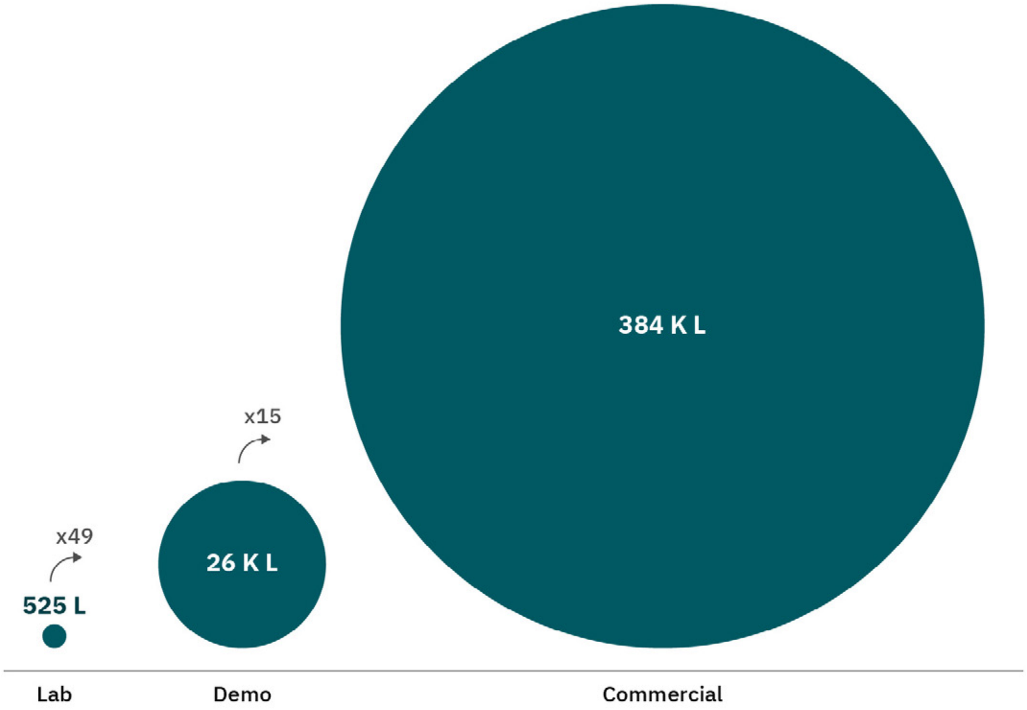


Figure 10. Average in-house fermentation capacity of producers at each scale

CMOs do not lend themselves to the same classification as they may operate at different scales on the same site. Most (74%) CMOs identified in this analysis are classified by more than one scale.

We can, however, calculate the average fermentation capacity for each combination of classifications, as shown in Figure 11. CMOs that can support commercial-, demo-, and lab-scale clients have the largest average fermentation capacity, at 634,000 liters.

Based on the information presented above, we estimate that the available global capacity for manufacturing fermentation-derived products currently stands at approximately 16 million liters of fermentation capacity across the 89 in-house producers and food-exclusive CMOs (Figure 12; lower bound).

The consolidated CMO database used in this analysis reveals an additional 53 CMOs that can manufacture food-grade products but are not food-exclusive as they also manufacture products for pharmaceuticals, industrials, or both (Figure 12). If we include these CMOs, global fermentation capacity increases by 250 percent to approximately 40 million liters (Figure 12; upper bound). However, pharmaceutical and industrial manufacturing covers many categories of products that compete for the same capacity, including vaccines, antibodies, nutraceuticals, biopolymers, and agricultural chemicals.

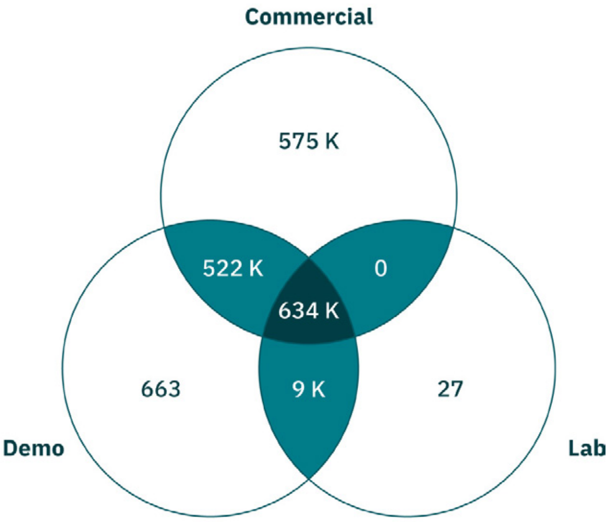


Figure 11. Average CMO fermentation capacity at each combination of scale classification

	CMO		Producers	Total	
	Food-exclusive manufacturing	Food plus pharma and/or industrials		In-house and food-exclusive manufacturing	In-house, food, plus pharma and/or industrials
	Lower	Upper		Lower	Upper
Number of Facilities	41	94	48	89	142
Capacity	8.2 MM L	32.0 MM L	7.5 MM L	15.8 MM L	38.5 MM L

Figure 12. Summary of fermentation-derived manufacturers

These categories typically involve manufacturing higher-margin products (up to 70% profit margins for pharmaceuticals). This poses a challenge for fermentation-derived product manufacturers in terms of accessing these facilities, suggesting that the estimated functional capacity is much closer to the lower bound of 16 million liters.

Estimate of annual product output based on global fermentation capacity

The significance of 16 million liters of fermentation-derived product manufacturing capacity can be more easily understood by converting this capacity in liters to estimated annual output in metric tons of alternative protein product. We estimated an annual output range using a simplified scenario and several assumptions, as described below. It is important to note, however, that numerous factors contribute to the overall output of any given manufacturing facility and those vary considerably across technologies and facilities.

For precision fermentation, we calculated an estimated output based on an assumed yield, number of campaigns, recovery efficiency, and the percentage of precision fermentation product in the final alternative protein product.

Yield:

The amount of a desired product produced by the microorganisms involved in the fermentation process is expressed in grams produced per liter of fermenter capacity for precision fermentation. Yield is influenced by various factors:

- Type of microorganism used.
- Concentration of nutrients.
- Temperature.
- pH.
- Duration of the fermentation process.

Maximizing yield is a key consideration for increasing efficiency and profitability in industrial fermentation processes. Final fermentation titers can range anywhere between 12–60 grams per liter.

Number of campaigns:

The total number of production runs performed using a particular set of operating conditions in a fermentation vessel or system over a specific period (in this case, a year).

The number of campaigns can be influenced by numerous factors such as the duration of each campaign, the downtime between campaigns, and the frequency of production. An average producer runs between 50 and 70 campaigns per year.

Recovery efficiency:

The percentage of the desired product that is successfully extracted and recovered from the fermentation process. Recovery efficiency can be influenced by various factors such as the nature and properties of the product, the fermentation conditions, and the recovery or downstream processing employed. Ideally, this would be around or greater than 80 percent. Recovery of the desired product can be even higher but requires additional operating expenditure (OPEX) with potentially diminishing returns.

For biomass fermentation, the output is more variable and highly dependent on the flow rate of the carbon source. Using the *21st Century Guidebook to Fungi* as a reference, we can make an approximation that per liter of fermenter capacity, we can expect an annual output of 39 kg of biomass product.[6] As stated above, the output for each process can vary widely depending on several factors.

Summary of scenario assumptions:

Biomass

Annual output of 39 kg per liter of fermenter capacity yield.

Precision

- 20 g per liter of fermenter capacity yield.
- 70 campaigns per year for each precision fermentation-focused company.
- 80% product yield.
- The total annual output estimate based on these parameters is 1.12 kg per liter of fermenter capacity annually.
- Assumed composition of precision fermentation ingredients is between 1 and 7% of the alternative protein end-product.
    - Upper bound: for every 1 kg of alternative protein end-product, there are 10 g of precision fermented cell product.
    - Lower bound: for every 1 kg of alternative protein end-product there are 70 g of precision fermented cell product.

Biomass to precision capacity split

40% biomass, 60% precision based on the distribution of known commercial facilities.

Global fermentation-derived product capacity

- Upper bound: 40 million liters (142 facilities including producers, food-exclusive CMOs, and CMOs classified as food standard and pharma and/or industrial).
- Lower bound: 16 million liters (89 facilities including in-house producers and food-exclusive CMOs only).

	Producers with in-house manufacturing and food-exclusive CMOs	Producers with in-house manufacturing and all CMOs that manufacture to a food standard
	Lower	Upper
Biomass	0.3 MMT	0.9 MMT
Precision	0.1 MMT	1.9 MMT
Total	0.4 MMT	2.8 MMT

Figure 13. Estimate of annual product output (in million metric tons, MMT)

In this simplified scenario, fermentation-derived manufacturing could have contributed an estimated 0.4–2.8 million metric tons of product to the total alternative protein market in 2022 (Figure 13). This estimate is within the range of the global consumption of alternative meat and alternative seafood consumed in 2022, consisting primarily of plant-based products.[7] This suggests that simple volumetric capacity is not necessarily a limiting factor; rather, there is a mismatch of current manufacturing capacity in terms of scale, technical capabilities, and geographic distribution of production capacity compared to demand and local needs of the stakeholders in this nascent industry.

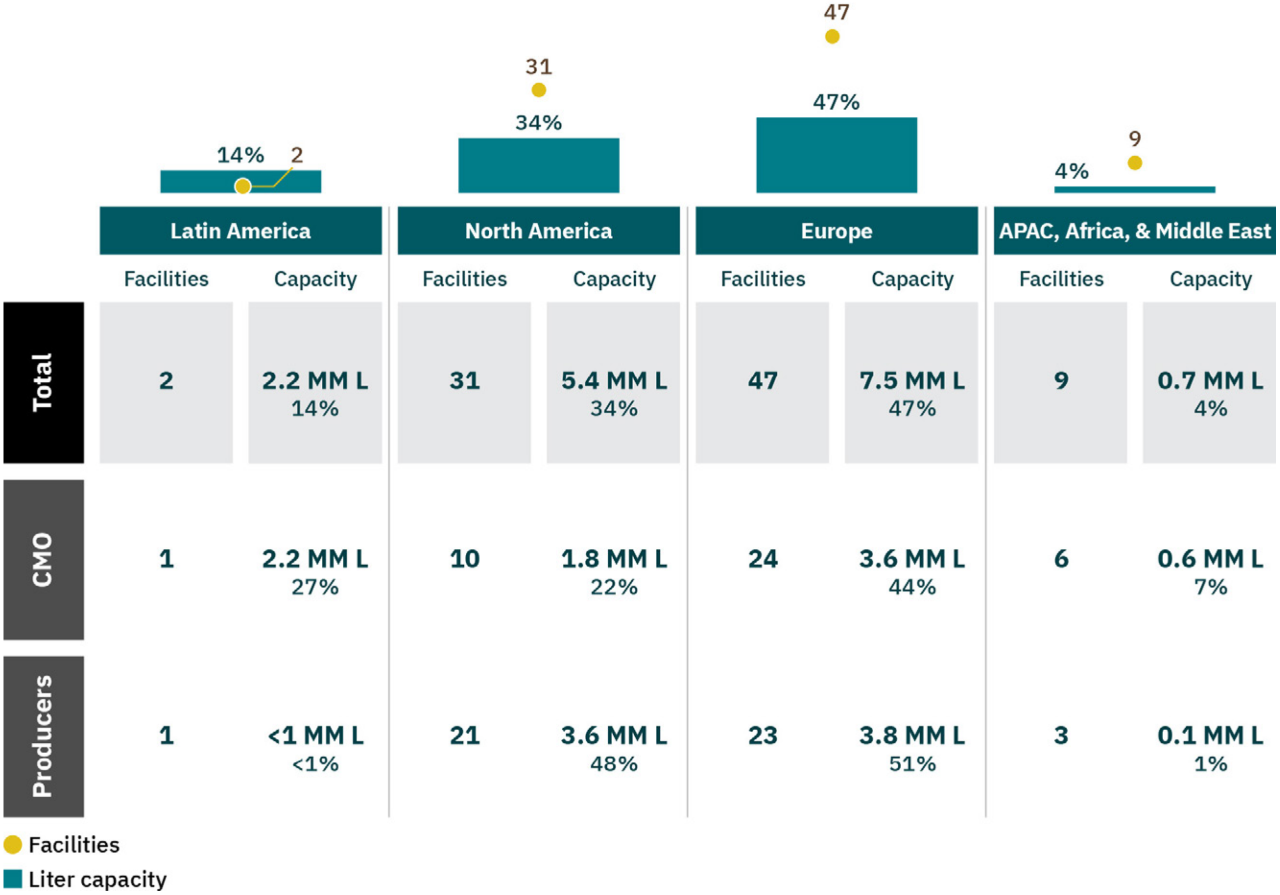
> *Converted to annual output, fermentation capacity could equal 0.4–2.8 million metric tons of alternative protein product.*

Challenges of existing manufacturing capacity and capabilities for fermentation-derived products

There is a notable lack of capacity outside of Europe and North America, particularly on a commercial scale.

The combined capacity of CMOs and in-house producers (Figure 14) is predominately concentrated in Europe, accounting for 47 percent of total capacity, and N. America, with 34 percent. Minimal capacity is registered outside of these regions; Mexico, Singapore, and South Korea are the markets with the largest capacity outside of N. America and Europe.

Only three commercial-scale, food-exclusive CMOs are registered in the APAC, Africa, and Middle East regions, two of which are in Singapore and one in Australia. As seen in Figure 15, there are other commercial-scale facilities situated outside of Europe and the Americas, however, these facilities manufacture food-grade products, as well as pharmaceutical and industrial products.



	Latin America		North America		Europe		APAC, Africa, & Middle East	
	Facilities	Capacity	Facilities	Capacity	Facilities	Capacity	Facilities	Capacity
Total	2	2.2 MM L 14%	31	5.4 MM L 34%	47	7.5 MM L 47%	9	0.7 MM L 4%
CMO	1	2.2 MM L 27%	10	1.8 MM L 22%	24	3.6 MM L 44%	6	0.6 MM L 7%
Producers	1	<1 MM L <1%	21	3.6 MM L 48%	23	3.8 MM L 51%	3	0.1 MM L 1%

Figure 14. Global fermentation-derived product capacity of food-exclusive CMOs and in-house producers

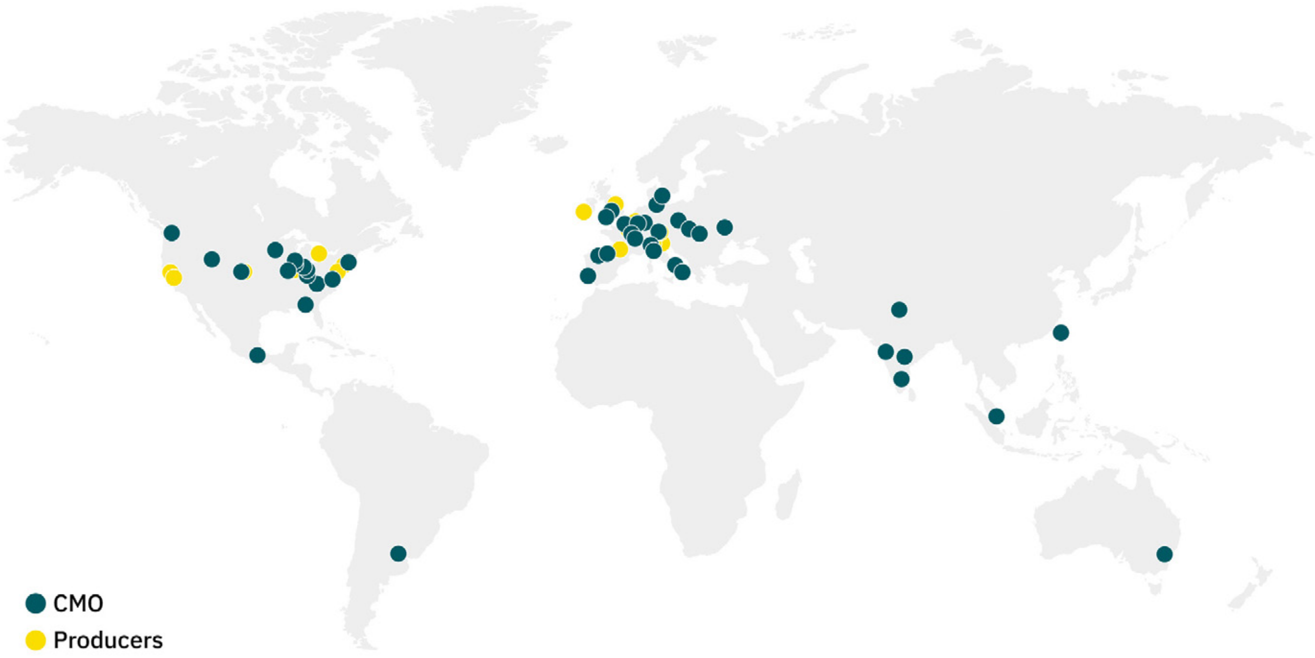


Figure 15. Geographic distribution of commercial-scale producers and CMOs classified as food standard and pharma and/or industrial

Even in markets at a higher level of biotechnological advancement (such as the U.S.), there is an opportunity to expand fermentation-derived product manufacturing capabilities.

Assuming that the producer outsourced capacity captured in Figure 8 can serve as an indication of CMO demand, there is a greater demand (regional demand for capacity vs. regional CMO availability) in N. America, APAC, Africa, and the Middle East compared to Europe or Latin America (Figure 16). This relationship suggests that producers in the United States seeking to outsource production may be more inclined to choose Europe or Latin America due to available capacity. Therefore, despite the U.S. containing a significant percentage of the global fermentation-derived product capacity (34%), there remains the opportunity to develop regional capacity for food-grade fermentation, particularly at commercial and demo scales.

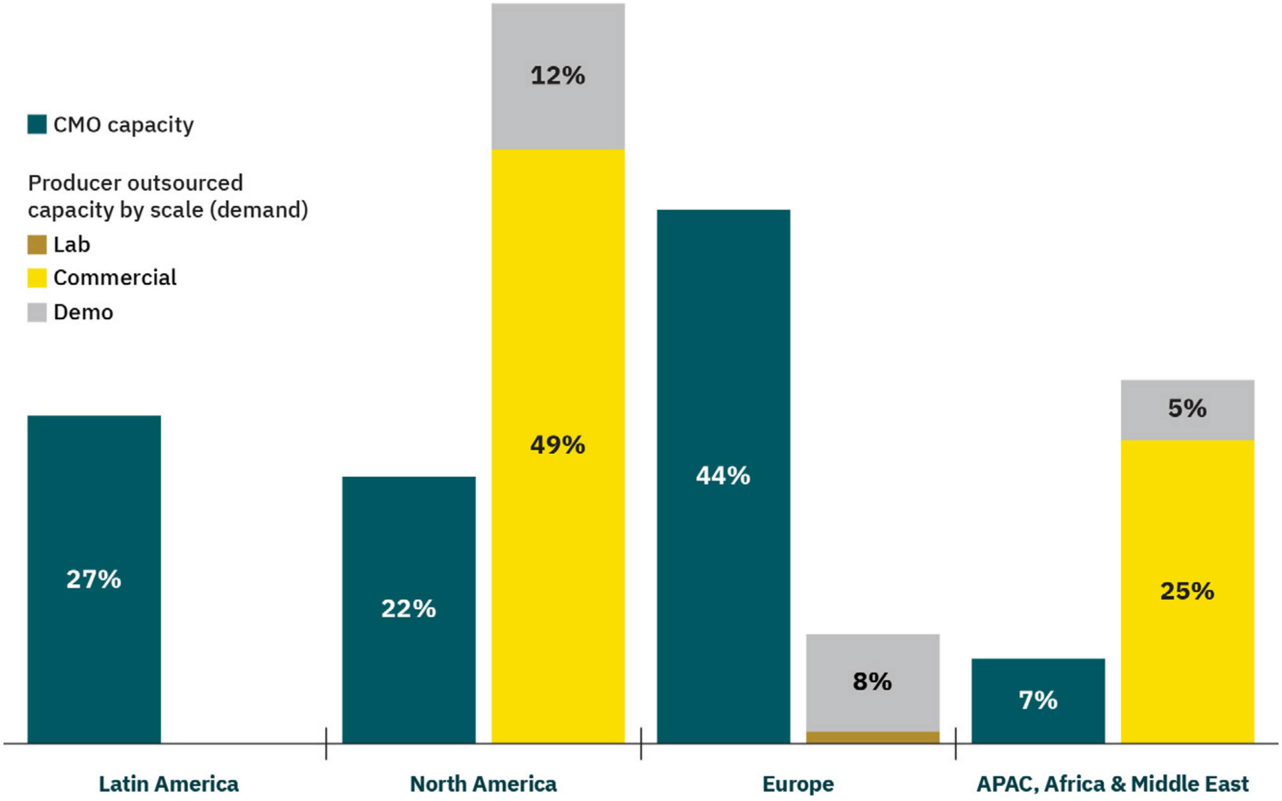


Figure 16. Regional food-exclusive CMO capacity (taken from Figure 14, %) compared to producer outsourced capacity by scale (Figure 8, expressed as a percentage of CMO capacity)

The limited availability of demo- and lab-scale CMO facilities may impact technological advancement and growth of the fermentation-derived products category.

One challenge involves access to facilities that enable a producer's transition from a viable product to commercialization. Companies with the equipment, knowledge, and engineering prowess required to address this bottleneck can support producers in scaling up their production and crossing the valley of death (Figure 17).

Throughout the 30+ interviews conducted for this report, industry experts across the value chain emphasized the need for facilities with the capabilities to scale up fermentation-derived product companies (such as lab and demonstration scale).

While these manufacturers may not directly contribute to the industry's overall volumetric needs, they collaborate with companies to refine their processes and assist in production. Some pursue contractual offtake agreements for commercialization in which companies agree to purchase a certain quantity of product produced,[8] a point that interviewees highlighted as being a fundamental step to secure further funding.

The most searched-for CMOs on the Capacitor database recognize the valley of death challenge and offer solutions to address it, including the ability to work with companies at lab and demo scales. Among the top 10 most-viewed facilities, all offer services at lab or demo scale, and four have a capacity at or below 120,000 liters—lower than the average capacity of 245,000 liters on the Capacitor database. With relatively small fermenter capacity, these facilities are particularly focused on guiding companies through the valley of death. A good example of one such facility is Bio Base Europe, a pilot plant facility that has successfully worked with many fermentation-derived product companies, including ENOUGH, to scale their production.

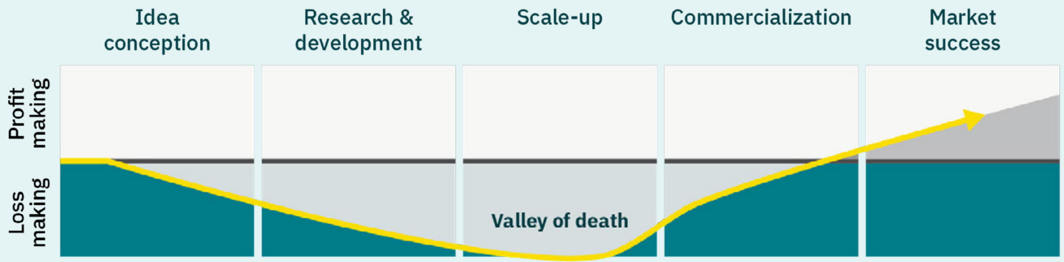


Figure 17. Valley of death visualization

The valley of death for companies refers to the challenging period during the commercialization of a new product. It takes this name because many companies fail to survive this phase, never making it to market.

Companies face several challenges here, such as scaling up from demo to commercial-scale production, ensuring product quality and consistency, developing cost-effective production methods, securing offtake agreements with foodservice, consumer product goods manufacturers, and retail companies, and obtaining funding for commercial-scale manufacturing.

These challenges can be particularly daunting for fermentation-derived product companies, as the complexity of the production process can be difficult to scale up without sacrificing product quality or incurring significant costs.

Qualitative indicators of the need for manufacturing capacity growth

Recent indicators, as outlined below, point to deficiencies in the existing manufacturing landscape to meet the future demand for fermentation-derived products as the alternative protein industry moves closer to certain milestones, namely taste and cost parity, which are expected to trigger an increase in consumer demand.

Increased governmental focus through incentive programs and tenders demonstrates an awareness by public actors for the need to develop and scale fermentation-derived product manufacturing capabilities and capacity to alleviate current supply chain gaps. For example:

- In January 2023, the Israel Innovation Authority released a request for proposals to establish infrastructure for the precision fermentation of microorganisms to develop alternative proteins, valued at around $13 million.
- In March 2023, the Biden administration in the U.S. announced new goals and priorities that emphasize the need to advance alternative proteins as a critical component of the bioeconomy.

A common industry perspective voiced through reports and thought pieces. Of the 30+ interviews conducted for this report, nearly all contributors echoed the need for increased manufacturing supply, with some emphasizing a particular need for demo-scale facilities to bridge the valley of death, as well as for commercial-scale manufacturing facilities in the U.S. to cater to future demand at an acceptable price point, influenced by successful capitalization on economies of scale.

Early signs of industry movement through projects and investments focused on bringing fermentation-derived products to market. Fermentation-derived product companies raised $842 million in 2022, with the number of unique investors in fermentation growing by 38 percent to 713 investors.[9] Liberation Labs, a fermentation-derived products-focused CMO has raised a $23.5 million seed round, the second largest seed round to date in the space.

Summary

The fermentation-derived product industry requires increased investment to meet growing demand. To fully capitalize on the market potential of fermentation-derived products, beyond volumetric capacity, organizations will need to develop the supply capabilities within this category. This includes sufficient CMO capacity in the U.S. to meet the demand of companies currently outsourcing production and facilities focused on crossing the valley of death. Currently, the estimated potential annual output of fermentation-derived product capacity from both CMOs and producers ranges from 0.4 to 2.8 million metric tons. Existing dedicated capacity will struggle to meet future demand for fermentation-derived products with respect to both geographic and lab- or demo-scale availability.

In the short term, companies should direct investments toward developing pilot- and demo-scale CMO capacity to help early-stage companies reach commercial-scale production. In the medium term, as fermentation technology matures and more companies reach commercial production scale, the focus should shift to developing commercial-scale capacity that caters to fermentation needs for producing alternative protein-based food products.

2

Strategies for scaling fermentation-derived product manufacturing capacity

The fermentation industry urgently needs to increase capacity at pilot and demo scale in the short term and begin procuring and developing opportunities now to ensure commercial scale for the long-term capacity needs of the industry. As shown in the framework in Figure 1, a variety of strategies exist for companies seeking to scale up production along each step of the technology development process (R&D to pilot, pilot to demo, and demo to commercial). This analysis focused on two critical strategic decisions from the perspective of the producer at each step in the scale-up process: 1) to partner with a CMO or build a proprietary facility, and 2) when building a proprietary facility, whether to build a greenfield facility or pursue brownfield development of an existing facility, with or without retrofitting the equipment. These decisions can be evaluated using six decision factors, which are broadly applicable to industry players but may be weighed differently depending on a company’s specific context (Figure 18).

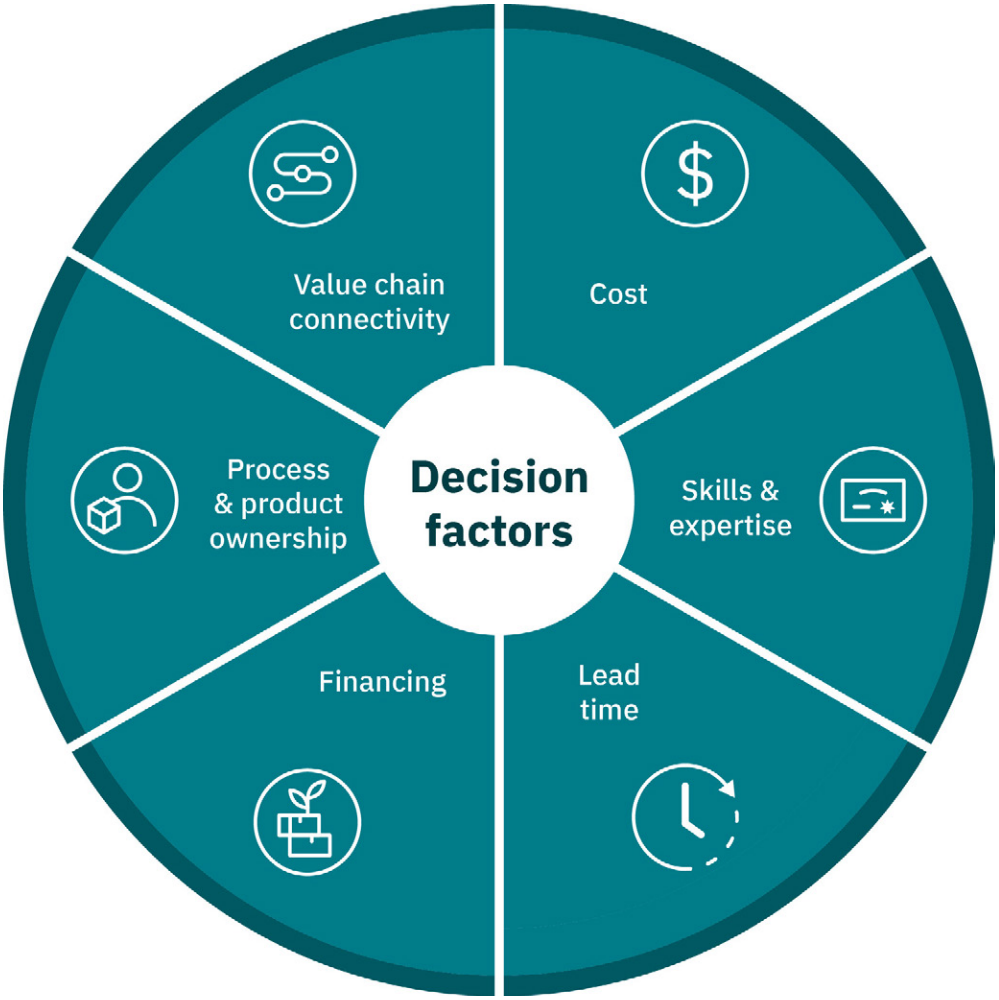


Figure 18. Decision factors guiding strategic decisions for capacity scale-up

Cost refers to expenditures for acquiring fermentation capabilities owned by the company or contracted from a third party (CMO), including up-front CAPEX and ongoing OPEX.

Skills & expertise refer to the knowledge, experience, and abilities required to successfully build, run, and develop the production process.

Lead time is the time required to implement the chosen manufacturing strategy, from planning through to production initiation.

Financing refers to obtaining funds (private, public, or both) for developing, building, or contracting fermentation capabilities, as well as the conditions attached to these funds.

Process & product ownership is the level of control a company aims to maintain over its product, processes, and techniques.

Connectivity relates to geographic proximity and/or integration with other players along the fermentation-derived product value and supply chains (e.g., feedstock suppliers, by-product customers, end-product consumers), incorporating co-location, contractual agreements, and informal arrangements.

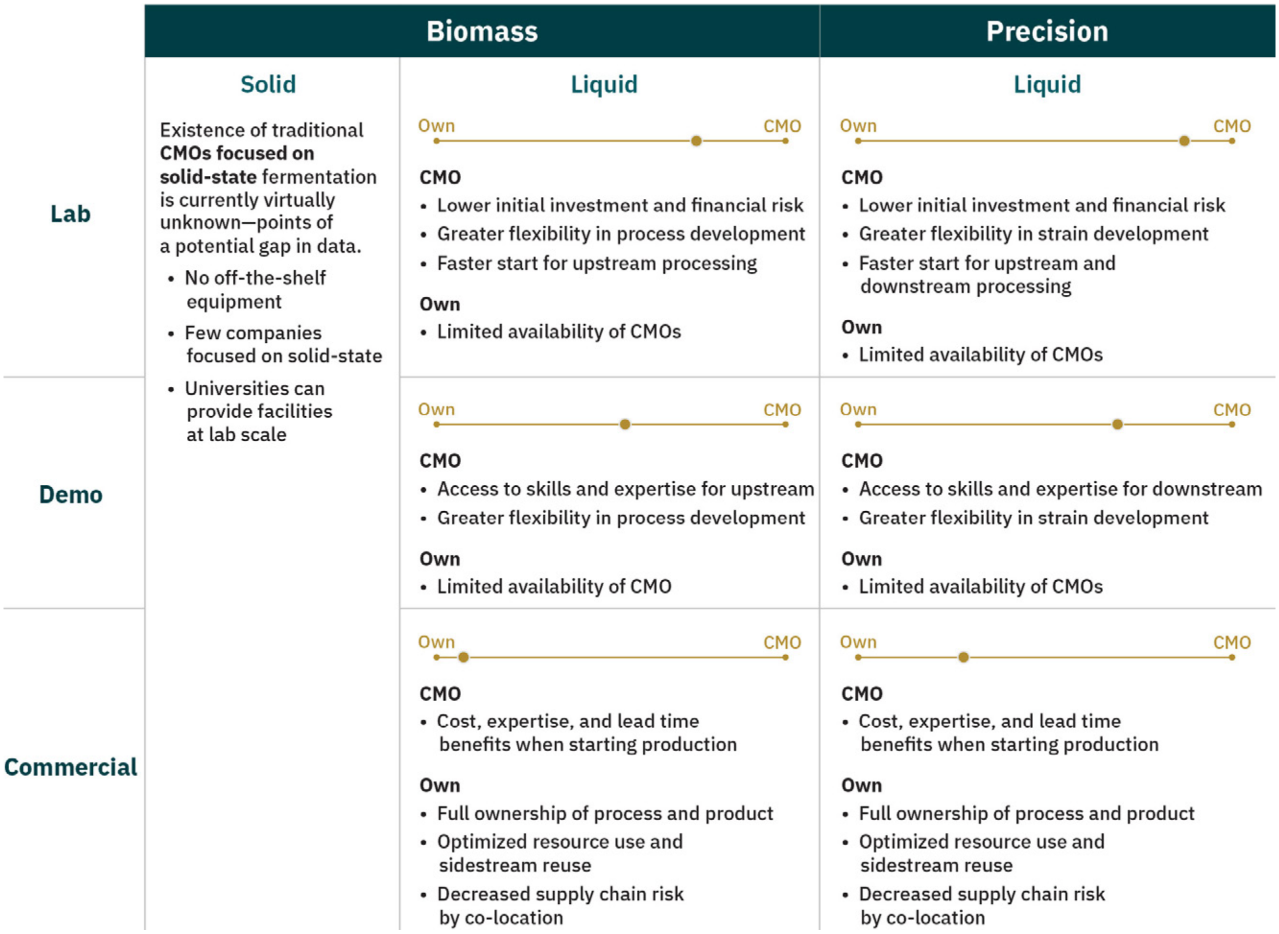
2.1 Evaluation of partnering with a CMO versus building a proprietary facility

The current state of the fermentation-derived industry reflects examples of the successful commercialization of products that have been produced both in partnership with a CMO and by building proprietary production facilities. Of the 30+ companies interviewed for this report, 50 percent are fermentation-derived companies that have partnered with a CMO (or vice versa) while 25 percent are companies with their own production facilities. The remainder provide material support, services, and investment to the industry.

In this section, we present the key considerations and insights from our survey, interviews, and desk research that influence the decision to partner with a CMO or build a proprietary (i.e., in-house) facility. First, we present a high-level overview of current tendencies among manufacturers (by fermentation type and scale) in selecting either of these options. Second, we break down the key considerations for each decision factor to inform companies facing this decision.

Current manufacturer tendencies: Partnering with a CMO vs. building a proprietary facility

The current tendency among manufacturers to either partner with a CMO or construct proprietary facility varies primarily by the type of fermentation they pursue and the scale of production (Figure 19). These two variables are directly related to the complexity of the fermentation process and equipment, the level of technological uncertainty and risk, and access to resources and capital.



	Biomass		Precision
	Solid	Liquid	Liquid
Lab	Existence of traditional **CMOs focused on solid-state** fermentation is currently virtually unknown—points of a potential gap in data. • No off-the-shelf equipment • Few companies focused on solid-state • Universities can provide facilities at lab scale	Own CMO **CMO** • Lower initial investment and financial risk • Greater flexibility in process development • Faster start for upstream processing **Own** • Limited availability of CMOs	Own CMO **CMO** • Lower initial investment and financial risk • Greater flexibility in strain development • Faster start for upstream and downstream processing **Own** • Limited availability of CMOs
Demo		Own CMO **CMO** • Access to skills and expertise for upstream • Greater flexibility in process development **Own** • Limited availability of CMO	Own CMO **CMO** • Access to skills and expertise for downstream • Greater flexibility in strain development **Own** • Limited availability of CMOs
Commercial		Own CMO **CMO** • Cost, expertise, and lead time benefits when starting production **Own** • Full ownership of process and product • Optimized resource use and sidestream reuse • Decreased supply chain risk by co-location	Own CMO **CMO** • Cost, expertise, and lead time benefits when starting production **Own** • Full ownership of process and product • Optimized resource use and sidestream reuse • Decreased supply chain risk by co-location

Figure 19: High-level summary of the current tendencies for manufacturers in the fermentation-derived product industry related to partnering with a CMO vs. building a proprietary facility

High-level industry insights

1 Capitalizing on CAPEX advantages is related to risk tolerance and the level of technology maturity

Early-stage fermentation-derived product companies prioritize faster and less capital-intensive options to mitigate resource constraints and early-stage technological risk. They leverage the expertise of experienced CMOs and invest more once they have demonstrated successful production at scale.

At a commercial scale, OPEX and process efficiency are critical factors to consider, with these metrics becoming even more pronounced as the scale of operations increases. As such, companies at commercial scale are more likely to build their own facilities to attain greater control and improve operational efficiency.

2 Lower complexity of biomass fermentation drives a faster transition to proprietary facilities

Generally, the advantage of partnering with a CMO to mitigate technological risk is exhausted more quickly for technologies with less complex downstream processing (DSP) requirements (Figure 20). A lower risk level for biomass fermentation leads companies to develop their own facilities earlier in process development and at a smaller scale compared to precision fermentation companies.

Solid biomass fermentation	**Liquid biomass** fermentation	**Precision** fermentation
Upstream output already in place, only requires freezing or cooking for microbe deactivation and transportation.	**Streamlined downstream processing** requires separation and drying or freezing for microbe deactivation and transportation.	Downstream processing involving **multiple tailored steps** such as separation, recovery, isolation, and purification depending on the target protein type.

Figure 20. Hierarchy of process complexity for biomass and precision fermentation

3 Limitations of CMO services and financing

The decision to partner with a CMO or build a proprietary facility is only relevant provided that CMO services and construction investments are both available. Although several CMOs for liquid-state fermentation exist, interviewees echoed that limited CMO capacity for liquid-state fermentation poses a major challenge, especially for early-stage companies to scale up. Based on our interview sample, very few CMOs provided solid-state fermentation services. Nearly all solid-state fermentation-derived product companies interviewed operate out of their own facilities, even when below commercial scale. Some companies at lab scale have used non-CMO facilities such as universities to gain access to third-party manufacturing equipment and the expertise of university staff for early process development.

Decision factor evaluation: Partnering with a CMO vs. building a proprietary facility

$ Cost

Companies interviewed for this project highlighted a production-scale threshold (Figure 21) at which they would consider transitioning from CMOs to proprietary facilities. Larger production volumes lower the cost per unit and dilute the fixed CAPEX involved in initially constructing and installing facilities. While CMOs can apply different pricing models, in general, the total cost of employing a CMO increases with greater volume and this makes the choice to build a proprietary facility more likely as a company achieves larger production scale.

While there is a tipping point, it differs based on the initial CAPEX investment to build a proprietary facility, which varies significantly depending on factors such as the intended fermentation type and the production scale. The table and case studies below (Figure 22) represent examples of CAPEX investments for proprietary manufacturing facility projects by companies and experts we surveyed and interviewed for this analysis. Though not complete, due to a lack of interview candidates at all scales and for all types of fermentation, the table indicates the relative CAPEX required across scales (lab, demo, and commercial) and for each type of fermentation. The companies in all the case studies built out brownfield manufacturing sites and installed new fermentation equipment.

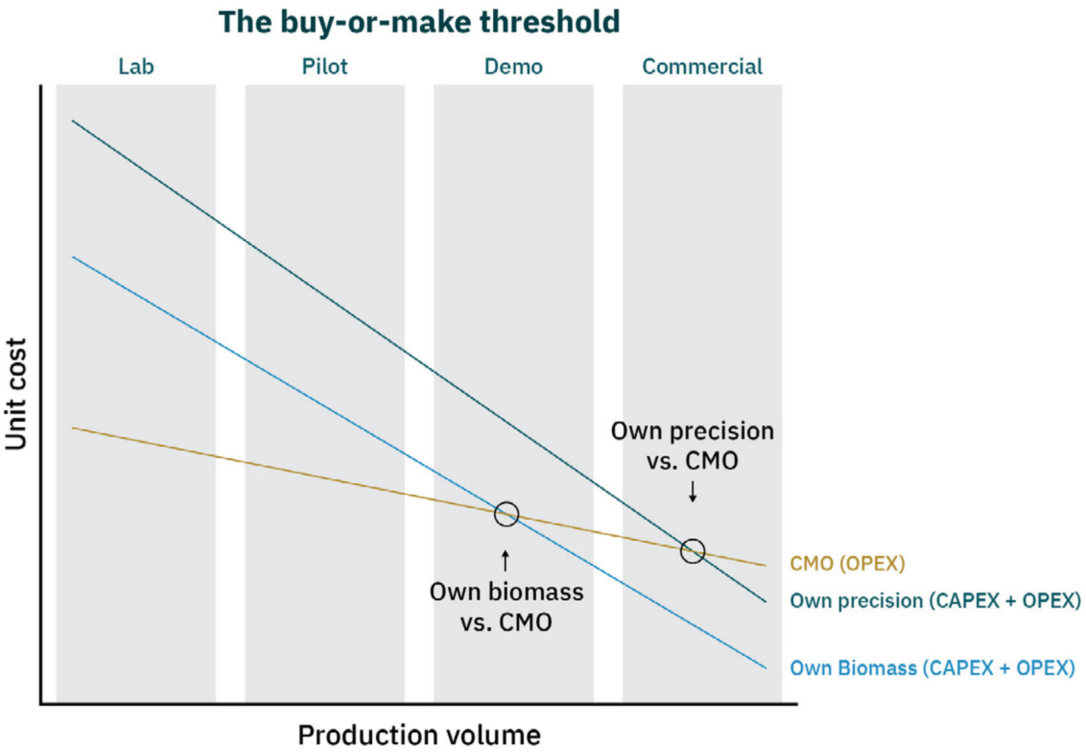


Figure 21. Buy or make threshold visualization based on production volume and unit cost[10]

	Biomass			Precision	
	Solid	Liquid		Liquid	
	Demo	Lab	Commercial	Demo	Commercial
Cap	2–5 K L	0.5 K L	300–500 K L	1.5–25 K L	200–750+ K L
Cost	$1–3 MM	$0.4–1 MM	$15–65 MM	$3–15 MM	$50–150+ MM
$/L	$600/L	$2000/L	$130/L	$600/L	$200/L

Lab/demo

Company A

- Type: CMO startup (precision)
- Features: Wealth of experience and deep industry connections
- Target: 1,000–5,000 liters
- Cost: <$5 MM

Demo/commercial

Company B

- Type: Ingredients producer (precision)
- Features: Active player in the alternative protein industry
- Target: 5,000–100,000 liters
- Cost: <$20 MM

Commercial

Company C

- Type: CMO startup (precision and biomass)
- Features: Commercial-scale ambitions backed by private investors
- Target: 100,000+ liters
- Cost: >$100 MM

Figure 22. CAPEX investment ranges for fermentation-derived product manufacturing facilities and supporting case studies

All projects are different and should be evaluated on a case-by-case basis. However, the following points can assist companies in understanding the overall cost-related considerations to evaluate when defining their manufacturing approach at each stage of development.

At lab scale, companies are focused on R&D strain development and piloting bioprocess strategies. At this stage, companies have typically started product development using laboratories owned by third-party CMOs or universities to avoid the high CAPEX requirements of a proprietary facility.

> *“Every project is a snowflake. Generalizing about the size of investment for facilities based on numbers that fail to consider highly specific contexts can be misleading.”*
>
> **– Matt Lucas, Tuatara Development Capital**

- Of the companies interviewed, all fermentation-derived protein producers started their strain development using laboratories and equipment provided by universities or CMOs.
- Universities often bridge the resource gap for companies by enabling strain and fermentation-derived process development. DSP at lab scale requires capital-intensive equipment such as centrifuges, filtration systems, and chromatography. According to our survey respondents, they spent 28 percent of their total greenfield project budget on DSP equipment vs. 10 percent for the land and building. The cost of the equipment itself and the team to operate it are often beyond the budget of companies in start-up mode.

At demo scale, companies are less sensitive to higher OPEX per unit output and tend to partner with CMOs to avoid high CAPEX requirements associated with building proprietary facilities.

- All the liquid precision and biomass fermentation-derived product companies interviewed have or are scaling up with support from a CMO. This gets them past the valley of death, a stage at which investment for a CAPEX-heavy project is harder to obtain.
- Biomass fermentation involves fewer DSP requirements compared to precision fermentation. Due to this, one expert considered a demo-scale facility as a step toward building a commercial-scale facility. A biomass demo facility can start by acquiring a single, commercial-size fermenter and gradually adding more fermenters to reach the desired commercial scale. This approach reduces the time and associated CAPEX for developing a new site.
- The decision to invest in a demo-scale facility depends on the company's strategy. Some experts interviewed stated that owning demo facilities provides flexibility for further strain development and portfolio diversification. In hindsight, others admit that they would not have built their own demo facility considering the investment required and the limited use case for a fermentation company that scales up production only once.

At commercial scale, while some experts emphasize the benefit of operating with fit-for-manufacturing facilities offered by CMOs, others argue that an organization can optimize operating costs by designing a facility that is fit for one distinct manufacturing purpose, as compared to a CMO catering to a diversified portfolio of end-products.

Precision fermentation

- Fermentation-derived product companies focused on precision fermentation tend to partner with CMOs longer than those focused on biomass—until OPEX cost disadvantages merit a switch to building their own production facility.
- As precision fermentation-derived product companies require more capital-intensive DSP equipment, CMOs sometimes require their precision-focused clients to invest (partially or fully) in DSP equipment, depending on the level of specificity of machinery required.
- The relatively higher level of profitability offered by precision fermentation-derived food products compared to biomass, and the intricate nature of DSP, can make these companies less sensitive to pricing. While CMOs may charge a high price per unit at this scale, precision companies may still consider this a viable option due to the importance of supplier expertise and skill level.

Biomass fermentation

- Fermentation-derived product companies focused on biomass fermentation tend to build their own commercial-sized facilities earlier than those in precision fermentation. All the biomass-focused companies surveyed explored paths to building their own manufacturing facility after they had scaled up their upstream and downstream fermentation processes.
- Fermentation-derived product companies can employ demo-scale production as a stepping stone toward achieving commercial scale capacity, particularly when their strategy involves scaling out rather than scaling up their manufacturing equipment. Solid (but also occasionally liquid) biomass fermentation-derived product companies often mentioned the approach in which the focus is on adding more production vessels rather than acquiring larger vessel sizes. Biomass fermentation-derived product companies with in-house production capabilities benefit from operating cost advantages and the freedom of choice to co-locate with feedstock or sidestream processors.

Other cost-related considerations

- Energy cost and availability can further influence the choice for a CMO in certain geographic locations, with the U.S. Midwest currently less expensive than Europe in this regard. One company setting up operations in East Africa highlighted the need to diversify its power supply to mitigate the risk of electricity outages.
- According to one expert, the chemical manufacturing experience in the APAC region, coupled with the generally lower cost of labor, presents a valuable opportunity for companies to establish commercial-scale manufacturing capabilities in the APAC region at a lower operating cost.

Skills & expertise

There is a clear argument to be made for companies to capitalize on CMO skills and expertise at the early stages of technological development and scale-up. The nature of these traits changes as operations scale up, with a greater reliance on production, management, and planning know-how to achieve effective operations (Figure 23). However, when partnering with a CMO, companies need to protect their intellectual property and maintain a degree of independence to develop and retain core capabilities in-house.

At lab scale, CMOs and universities provide a platform for developing product concepts.

- All the companies interviewed began their product development process in collaboration with a university, providing them with the necessary equipment and the ability to explore new product concepts while leveraging cutting-edge research from professors.
- Many have used university collaboration to develop a proof of concept for a new product, especially those requiring expertise related to strain development.
- This suggests that universities are an important driver for industry growth by acting as incubators that provide resources, equipment, and enable product development.

At demo scale, fermentation-derived product companies leverage CMO knowledge and experience related to scaling-up, production challenges, and engineering creativity.

- Nearly all the liquid biomass companies interviewed scaled up with the support of a CMO, selecting a partner based on expertise over price.
- When scaling up, fermentation-derived product companies face several process-specific challenges that CMOs can address with their skills and experience (Table 1). Personnel with relevant training and industrial experience are in demand and can be difficult to identify, recruit, and relocate. Many of these desirable skills come with on-the-job experience. Having this depth and breadth of knowledge within a company's own team can prove challenging and costly.

Early-stage	Scale-up	Commercialization
Companies in the lab phase	**Companies in the demo phase**	**Companies in the production phase**
• Strain development	• Downstream process engineering	• Continuous manufacturing
• Microbiology	• Formulation optimization	• Project management
• Fermentation optimization	• Food science expertise	• Resource optimization
		• Waste efficiency

Figure 23: Expertise required at the different stages of development

Table 1. External skills and expertise at demo and commercial scales

Upstream	Understanding and adapting to the technical and bioprocessing challenges that occur at larger volume fermentations. Knowing how to prevent contamination when preparing fermentation feedstocks and growing microbes across increasingly larger seed step volumes while managing increased heterogeneity in the bioreactor environment. Providing operational know-how related to the technical equipment and machinery involved.
Downstream	Closing gaps in process knowledge to maximize output yields when scaling up, especially in precision fermentation.
Process efficiency	Maintaining stable yield or titers when scaling up by efficient use of USP and DSP equipment.
Problem-solving	Creative engineering to solve technical problems related to scaling up (e.g., viscosity) and to select the right mix of DSP equipment and bioprocess parameters to achieve the same end-product at a higher scale with a lower cost, especially as DSP at lab scale involves more expensive/specialized equipment that can be prohibitively expensive (or benchtop equipment that is not completely representative of commercial scale separation and processing technology).
Equipment	Offering a range of equipment and knowledgeable operators, with some covering 85% for DSP and many open to investing in additional equipment based on use commitments.

Counterpoint: CMO dependency

Making use of a CMO at this early stage may compromise the opportunity to develop core capabilities in-house and lead to dependency down the road. Most CMOs do not allow fermentation client company scientists to visit their facilities or oversee production runs.

Experts note that fermentation-derived product companies face a challenge related to process and documentation expertise. Prior dependence on a CMO means that many lack familiarity with the intricacies of technical processes and the related documentation needed to satisfy risk-averse investors.

At commercial scale, key differences emerge between precision and biomass fermentation.

Precision fermentation companies tend to leverage the manufacturing expertise provided by CMOs for as long as operating costs offer sufficient profit margins. CMOs and precision fermentation-derived product companies often complement each other’s areas of expertise, with CMOs providing the manufacturing skills and client companies providing the strain-development expertise.

Biomass fermentation companies tend to rely on in-house expertise earlier and they leverage that in-house expertise when setting up their own production processes upon scaling up.

Lead time

Building a proprietary fermentation manufacturing facility requires more lead time than working with a CMO facility. Among the companies surveyed that operate their own facilities, some cited lead times from under one year for building out lab or demo facilities to up to three years for commercial-scale operations (Figure 24).

Biomass (proprietary facility)

- Lab/demo: 7–18 months
- Commercial: 17–24 months

Precision (proprietary facility)

- Lab: 12–36 months
- Commercial: 24–36 months

Key steps

- **Site design** – from planning stages FEL1 to FEL3 (front-end loading/index engineering)
    - **FEL1:** Block flow design to identify critical needs and objectives of project
    - **FEL2:** Define scope, site, preliminary design, and preliminary CAPEX estimate
    - **FEL3:** Identify site and layout, define process flow diagram, and specify equipment
- **Permits and licenses** – from local authorities
- **Equipment lead time** – up to 12 months for essential equipment such as fermenters
- **Site construction and installations** – to achieve an integrated production process
- **Commissioning** – integrate and test equipment within the production process

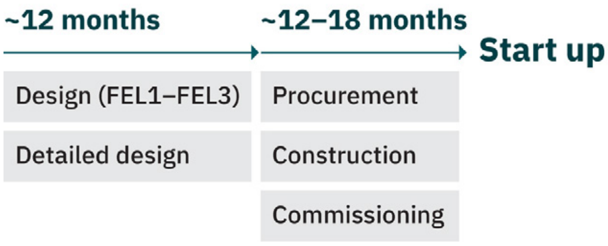


Figure 24. Lead times and steps to build proprietary fermentation-derived protein facility

While engaging a CMO can be a faster option, setting up the integrated process still demands time. Purchase lead times, installation, and commissioning of specialized DSP equipment prolong the wait to start operations, especially for fermentation-derived product companies that need to invest in DSP for the CMO. One expert noted that it took several months just to acquire, install, and commission a spray dryer.

Further time-related risks

While CMOs can be leveraged to rapidly operationalize production, availability remains a constraint. Until more CMOs enter the market, many companies seeking to produce at a commercial scale may need to rely on their own facilities.

Financing

As the fermentation-derived product category is still nascent—with profitability and demand yet to be established—financing can be difficult to obtain. Investors generally prefer capital-light investments achieved by partnerships with CMOs, provided that intellectual property is sufficiently protected.

Challenges

- The lack of bankability among fermentation-derived product companies seeking financing to build their own facilities was a significant concern among interviewees, particularly investors. Uncertainty surrounding sales and demand figures for fermentation-derived alternative proteins raises concerns about the ability to ensure sufficient return on investment (ROI).

- The risk profile of venture capital investments is not well-suited for financing projects requiring physical infrastructure or facilities. The limited potential for significant returns relative to the potential for losses renders such projects less attractive to venture capital firms.
- Infrastructure investors tend to prioritize risk management and demand clear communication from early-stage producers to ensure a reliable ROI. However, many companies fail to recognize the level of effort required to effectively derisk the investment and provide a realistic understanding of the cost structure and potential ROI.

Strategies

- **Partnering with an established anchor client** (established retailer, manufacturer, or foodservice player) when seeking funding to build facilities can reduce the risk of default for potential investors and provide assurance of ROI.
- **Numerous small producers sharing a production facility** can make facility infrastructure investments less risky by providing greater assurances of ROI. Similarly, a company may choose to construct capacity and bioprocess capabilities that allow them to devote a portion of the facility efforts to contract manufacturing.
- **Diversifying the customer portfolio** across different end-products can create more stable and consistent revenue streams, therefore providing assurance of ROI.
- **Avoiding lock-in by maintaining technological flexibility** through a modular setup that can easily be modified to manage the risk of default and enable return recovery in case a certain technology is not viable.
- **Creating detailed process-related documentation** throughout the entire value chain to satisfy the required level of planning and communication required by risk-averse investors.
- **Seeking cross-sourced funding** opportunities that combine public and private investors to reduce risk and foster investment. Experts note that companies will need the motivation of government funding to finance production expansion.
- **Identifying a precedent** in a comparable business case to demonstrate the ROI potential to otherwise skeptical investors with the aim of accelerating investment and growth, such as vertical farming or the plant-based alternative protein industry.

Further financing considerations

Due to the limitations of financing production capacity, investors have shifted their focus to enabling technologies for fermentation manufacturing across the value chain and on improving process efficiency rather than volume. This shift may exacerbate the challenge to raise funds solely for consumer brands or manufacturers.

A jumpstart from the public sector

The sheer novelty of this technology has contributed to an overall risk perception among private investors. While public funds can help reduce the financial risk, universities can play a role in further reducing risk by providing space for experimentation and development at early stages of development—or even as a CMO for scaling up as in the case of the University of Illinois' Integrated Bioprocessing Research Laboratory.

Process & product ownership

Successfully developing a fermentation-derived product typically involves innovations in biology and fermentation processes. Many of these fermentation innovations occur at the level of process design and control. Companies can protect and control their intellectual property by keeping production in-house.

Key considerations

Intellectual property: While all investors mentioned the importance of knowledge sharing in the fermentation-derived product industry, they also emphasized a need to protect intellectual property. As fermentation-derived product companies are reluctant to reveal their innovations (fermentation conditions, processes, and microbial strain), they have a strong desire to establish proprietary facilities as early as possible. However, collaboration with CMOs mainly concerns process expertise, as CMOs usually do not analyze or retain the genomic identity of the clients' microbial strains. Even with nondisclosure agreements in place, there is always a risk of information spillovers.

Efficiency: CMO equipment can limit the potential for optimizing process efficiency as it needs to be used to serve diverse end-products rather than being tailored to a specific purpose (though not all CMOs are generalists).

Core capabilities: Building essential skills and expertise in-house is crucial for fermentation-derived product companies to maintain operational independence. Utilizing a CMO often means that the external team is not on site during production. The CMO business model often precludes the possibility of scientists experimenting and running batches themselves or learning from contaminated or failed batches. This model and relationship can also be challenging because, by handing over control of the process, CMOs need to manage the responsibility and cost implications when a batch becomes contaminated or fails.

Sustainability: Full product and process ownership enables fermentation-derived product companies to incorporate environmentally sustainable production practices including flexibility in utilizing used equipment, incorporating renewable energy sources, or leveraging other industries' sidestreams as a source of feedstock.

Value chain connectivity

Some companies that partner with CMOs take advantage of co-locating with research centers and feedstock sources. A number of the companies interviewed also note that they further optimize their cost structure by co-locating with sidestream processors or the point of sale.

Key considerations

Talent: Many CMOs co-locate with universities to benefit from proximity to research centers, evolving knowledge, and sources of new talent. Start-ups collaborating with universities emphasize the importance of experience and support provided by research groups.

Sidestreams: Some companies leverage co-location advantages for sidestream treatment. One of the interviewed companies channels its output sidestreams as inputs for ethanol production.

Feedstock: Companies see co-location with feedstock as essential when selecting a site for manufacturing. For example, ENOUGH Food co-located their facility in the Netherlands with Cargill to ensure an efficient feed source, as well as supporting the zero-waste advantages provided by ENOUGH's product.[11] Partnering with the right CMO can grant access to locations that may not otherwise be available. Experts note that CMO candidates in parallel industries, such as brewing, often have good access to feedstocks due to the nature of their business, of which fermentation-derived product companies can take advantage.

Market proximity: Some fermentation-derived product companies seek to decentralize production to enable proximity to the point of sale, which is especially relevant for perishable products.

Summary

Early-stage fermentation-derived product companies prioritize faster and less capital-intensive options to mitigate resource constraints and early-stage technological risk by leveraging the expertise of CMOs. These companies tend to invest more on in-house capabilities only after they have scaled up production. However, the advantage of partnering with a CMO to mitigate risk is generally exhausted more quickly for technologies with fewer DSP requirements such as solid-state or biomass fermentation. For those that endeavor to build out a proprietary facility, another set of strategic decisions needs to be made: whether to build a new facility or use an existing facility and whether to buy new equipment or retrofit equipment that has been previously used. We will review these decisions using the same factors in the next section.

2.2 Evaluation of greenfield vs. brownfield development and buy new equipment versus retrofitting equipment

With the aim of reducing the time, cost, and complexity of developing manufacturing capabilities, fermentation-derived product companies generally seek to repurpose existing infrastructure, either entire production sites or specific equipment. While using existing buildings and infrastructure is relatively straightforward and common, the possibility of retrofitting used equipment is predicated on fulfilling several specific technical and economic requirements related to the fermentation type and stage of development, as outlined herein.

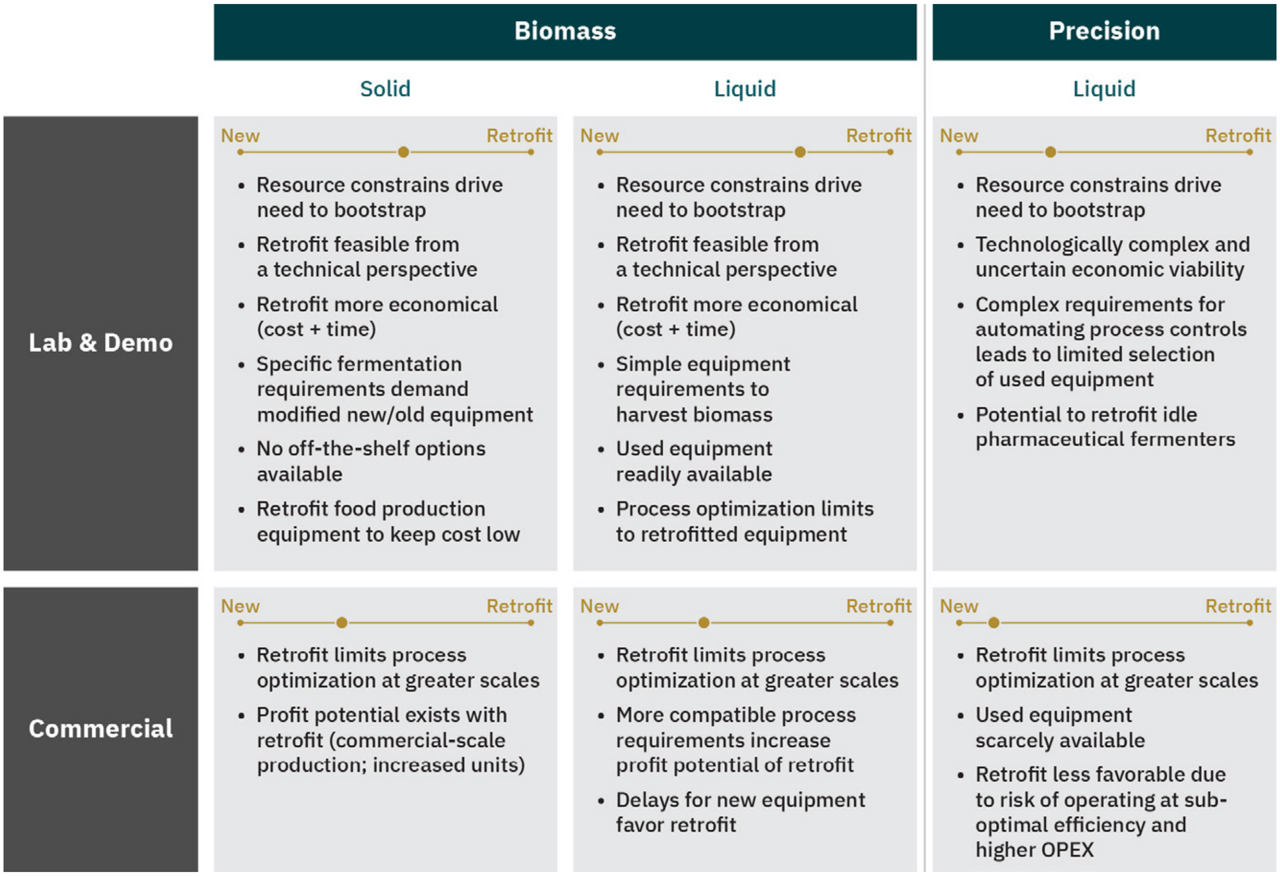
Current manufacturer tendencies: Buying new equipment vs. retrofitting used equipment

Developing brownfield vs. greenfield sites:

There is a compelling case for utilizing existing manufacturing sites. Most of our interview partners have pursued this option rather than building a greenfield site to take advantage of significantly reduced CAPEX investments, accelerated time-to-market, key utilities already being in place, and many suitable sites available, such as free space in industrial parks or former facilities.

Buying new vs. retrofitting used equipment:

Success cases show that retrofitting used equipment for fermentation is feasible from a technical perspective, particularly for solid and liquid biomass fermentation. Figure 25 summarizes the current manufacturer tendency to purchase new equipment or retrofit used equipment across production scale and fermentation type. In general, early-stage fermentation-derived product companies are more likely to consider or attempt to retrofit equipment as they have a greater need to bootstrap operations due to resource constraints. However, due to the complex technical requirements of precision fermentation equipment, experts are skeptical of the economic viability of retrofitting for precision fermentation at all scales. Since blueprints for retrofitting fermentation equipment are not yet available on the market, having access to the required skills and expertise in-house plays a crucial role in making the retrofit option viable. Table 2 summarizes the advantages and challenges of retrofitting equipment for fermentation-derived product production.



	Biomass		Precision
	Solid	Liquid	Liquid
Lab & Demo	New Retrofit • Resource constrains drive need to bootstrap • Retrofit feasible from a technical perspective • Retrofit more economical (cost + time) • Specific fermentation requirements demand modified new/old equipment • No off-the-shelf options available • Retrofit food production equipment to keep cost low	New Retrofit • Resource constrains drive need to bootstrap • Retrofit feasible from a technical perspective • Retrofit more economical (cost + time) • Simple equipment requirements to harvest biomass • Used equipment readily available • Process optimization limits to retrofitted equipment	New Retrofit • Resource constrains drive need to bootstrap • Technologically complex and uncertain economic viability • Complex requirements for automating process controls leads to limited selection of used equipment • Potential to retrofit idle pharmaceutical fermenters
Commercial	New Retrofit • Retrofit limits process optimization at greater scales • Profit potential exists with retrofit (commercial-scale production; increased units)	New Retrofit • Retrofit limits process optimization at greater scales • More compatible process requirements increase profit potential of retrofit • Delays for new equipment favor retrofit	New Retrofit • Retrofit limits process optimization at greater scales • Used equipment scarcely available • Retrofit less favorable due to risk of operating at sub-optimal efficiency and higher OPEX

Figure 25. Buying new vs. retrofitting used equipment

Table 2. Challenges and advantages of retrofitting used equipment for fermentation-derived product production

Challenges	Advantages
high degree of variation in the type, state, and usability of the target equipment	cost savings for suitable production types and target technologies
access to the expertise needed to adapt and operate the equipment	enabling the viability of early-stage technology using limited resources to overcome risk and investment constraints
cost and time investment required to retrofit	reliance on skills and expertise over large up-front capital investments
viability and cost of transporting large equipment	reduced time-to-market for target technologies and suitable production types
adaption efforts for more complex technology (especially for precision fermentation)	highly suitable for downstream processing (especially biomass fermentation)
sub-optimal or variable efficiency once retrofitted	

Decision factor evaluation: Greenfield vs. brownfield development and buy new vs. retrofitting equipment

$ Cost

Fermentation-derived product companies have achieved up to tenfold CAPEX savings by retrofitting fermentation equipment instead of buying new equipment. Companies also attain significant cost savings by building out existing brownfield sites rather than breaking ground on a greenfield facility.

Developing greenfield vs. brownfield sites

Acquiring and building out a brownfield site has saved fermentation-derived product companies both time and CAPEX. There are several key considerations for pursuing the brownfield route:

Lower impact of CAPEX-to-technical components ratio: The cost of a greenfield project can vary substantially. Infrastructure investors referenced an estimated ratio of total CAPEX for setting up operations to major technical components costs (Lang factor) of 6 for an emerging industry (compared to ~3–4 for established ones). With savings achieved from acquiring existing technical facilities, brownfield sites significantly reduce the overall cost of setting up facility operations, which are particularly high for such nascent sectors.

Access to utilities: All the fermentation-derived product companies and CMOs interviewed have or are planning to utilize brownfield sites for new facilities and identified access to existing utilities such as water, electricity, and wastewater treatment as major cost drivers.

Long-term operating costs: OPEX can be higher due to the physical limitations set by the age of the site, its prior purpose, location, or resource consumption.

Buying new vs. retrofitting used equipment

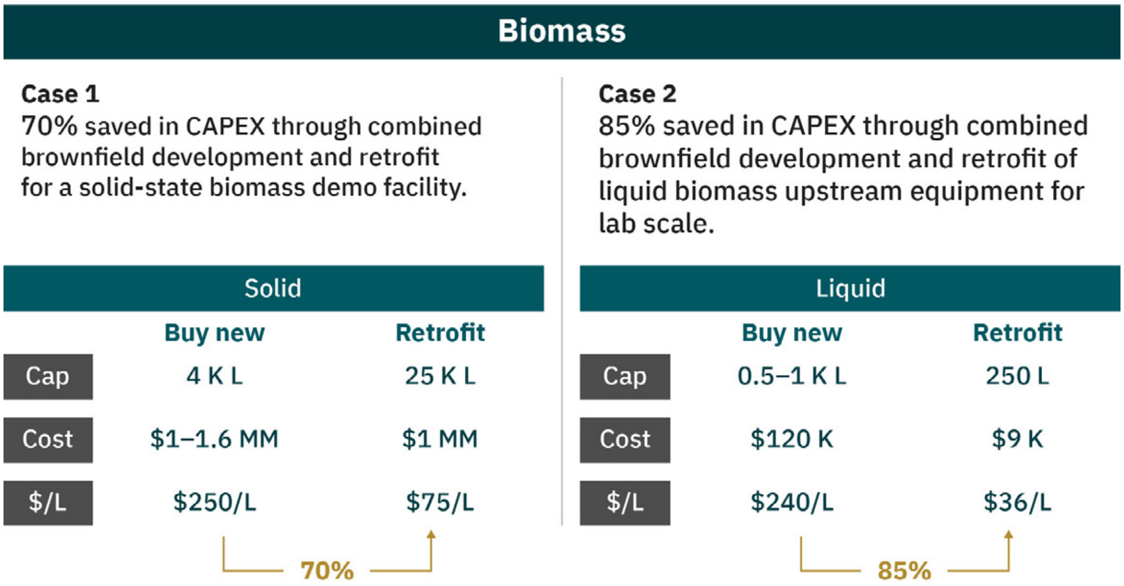
Companies in the fermentation space generally seek to retrofit fermentation equipment to save time and money; however, cost savings vary significantly between biomass and precision fermentation. Using real-world examples, Figure 26 summarizes the potential CAPEX reduction of retrofitting.

Liquid biomass: The fermentation-derived product companies interviewed acquired key equipment secondhand for as much as 1/10th the cost of new equipment. Several interviewees highlighted the savings potential of retrofitting used equipment from breweries at around 30 percent less than buying new. Experience shows that, compared to the broad potential held by core fermentation equipment, DSP equipment has rarely proven to be suitable for retrofitting.

Liquid precision: Fermentation-derived companies and CMOs express more skepticism about retrofitting equipment for precision fermentation. The economic viability of retrofitting core equipment for precision fermentation is less clear, and the availability of suitable equipment options is limited due to the complex technical functionality required for both the fermentation and DSP equipment.

$ *Cost limitations of retrofitting equipment*

- The investment required to retrofit the equipment for its intended use.
- Availability and cost of the expertise to retrofit.
- Efficiency differentials between new and retrofitted equipment.



Biomass

Case 1
70% saved in CAPEX through combined brownfield development and retrofit for a solid-state biomass demo facility.

Solid	Buy new	Retrofit
Cap	4 K L	25 K L
Cost	$1–1.6 MM	$1 MM
$/L	$250/L	$75/L

70%

Case 2
85% saved in CAPEX through combined brownfield development and retrofit of liquid biomass upstream equipment for lab scale.

Liquid	Buy new	Retrofit
Cap	0.5–1 K L	250 L
Cost	$120 K	$9 K
$/L	$240/L	$36/L

85%

Figure 26. CAPEX saved by brownfield development and retrofitting

Lead time

Companies can halve the lead time to start an independently owned fermentation facility by investing in a suitable brownfield site and retrofitting equipment.

Developing greenfield vs. brownfield sites

All interviewees identified quicker production start-up times as a major benefit of acquiring an existing brownfield site. Greenfield projects involve more steps and time to build, from breaking ground and constructing a new building to designing detailed engineering processes and installing utilities. Additionally, experts note that obtaining the required permits from public authorities represents a major bottleneck for fermentation-derived product companies seeking to build a greenfield site.

The companies interviewed cite lead times as low as six months when building out a brownfield site. Conversely, interviewees estimated it takes 18 to 36 months to install new equipment and build out a greenfield site depending on the scale of operations. Brownfield options may be limited by geography and the opportunity to acquire a brownfield site suitable for fermentation-derived food products will vary by location and previous facility application.

Buying new vs. retrofitting used equipment

Lead time for obtaining new or retrofitting used equipment is highly variable and linked to market dynamics and equipment type. Experts have emphasized equipment lead time as one of the major bottlenecks for setting up production, with lead times of 12 months or more for fermenters depending on supply chain constraints. Retrofitting used equipment can accelerate the time to start operations depending on the effort for the required modifications, which also varies, as described below.

Biomass: Biomass-focused fermentation-derived product companies reported that retrofitting can take up to 6 months for lab and demo scale and 13 to 18 months for commercial scale operations, as shown in Figure 27. The time required depends on the state of the equipment and its intended use in the production process, with refinishing being the most time-consuming step, as shown in Figure 28.

Biomass

	Solid	Liquid	
	Demo	Lab	Commercial
New	12–18 months	12 months	17–24 months
Retrofit	0–6 months	6 months	13–18 months

Figure 27. Lead time to buying new vs. retrofitting equipment

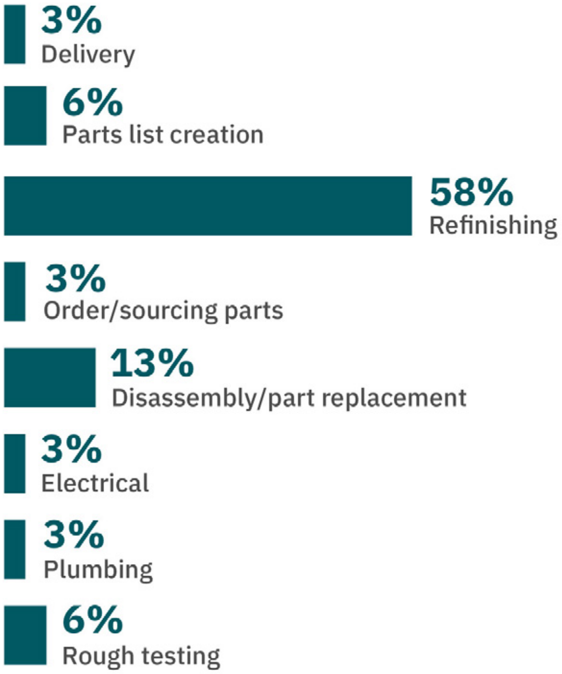


Figure 28. Time allocation for retrofit steps for a biomass fermenter

Precision: The extensive effort required to retrofit equipment for precision fermentation processes makes it difficult to estimate time saved by retrofitting.

Skills & expertise

Effectively retrofitting equipment or developing a brownfield site requires several specific skillsets and areas of expertise. Manufacturers need to be able to:

- Identify viable candidates for retrofit/brownfield development.
- Perform the equipment retrofit/site adaptation or manage the process.
- Integrate retrofitted equipment into the production process.

Greenfield vs. brownfield sites

Developing a greenfield or brownfield site requires specific knowledge of the target manufacturing process along with experience in building out fermentation facilities, with one major difference for greenfield developments: the prerequisites for acquiring additional funds and for obtaining required permits. Investors have extensive documentation requirements that pose a challenge to companies attempting to produce at commercial scale, which is compounded among those previously reliant on a CMO. Companies pursuing this option need to have a clear understanding of their manufacturing processes to plan and design the new facility accordingly and secure financing. Companies should be able to answer the following questions:

- What raw material goes into the process and what sidestreams and wastestreams come out?
- What input and output quantities are involved?
- What will be required to scale in the future?

Experts claim that the lack of expertise required to plan and execute greenfield development can be prohibitive. For brownfield developments the lead time and CAPEX savings may justify the additional cost of acquiring external expertise.

New vs. used equipment

The viability of retrofitting used equipment will depend on whether fermentation-derived product companies have the skills for executing the steps outlined in Figure 29. For cases in which the relevant technical expertise is lacking, the risk of incurring a future cost disadvantage may become too great, making the buy new option more suitable.

Financing

Investors in the fermentation-derived space have preferred to pursue capital-light investments due to the financial risks associated with companies at lab and demo stages using unproven, novel technology. As such, fermentation-derived companies generally seek to reduce overall costs by pursuing brownfield and retrofit options at earlier stages. Depending on the scale of operations, the availability of suitable equipment, and the expertise these companies possess, pursuing an in-house route by retrofitting has allowed numerous fermentation-derived product companies to acquire and commission used equipment without the need for outside financing from investors.

From a financing perspective, experts highlight that retrofitting is a less suitable option for fermentation-derived product companies setting up commercial-scale facilities. Equipment that has not been optimized for its end use is likely to place operational limitations on efficiency, operating costs, and potential ROI.

Process & product ownership

As noted, brownfield sites as well as retrofitted equipment can limit process optimization. Having originally been designed for a different purpose, such equipment can present physical and technical restrictions that typically result in lower overall efficiency or more downtime. In addition, retrofitted equipment can require more manual input and labor costs to operate compared to new equipment, restricting the overall level of facility automation.

On the other hand, the cost advantages offered by using brownfield sites and used equipment can outweigh losses in process control and operational efficiency. Ultimately, the relevance of these limitations will depend on how much flexibility existing sites and retrofitted equipment provide when setting up the manufacturing processes.

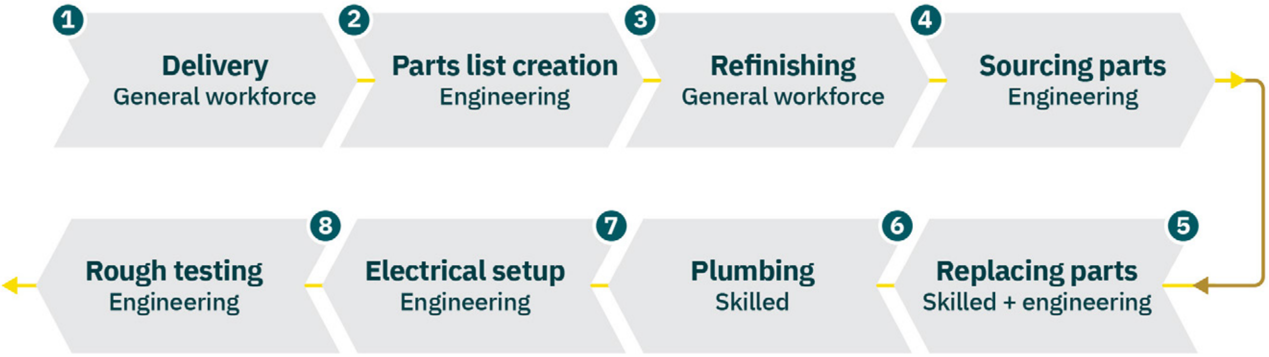


Figure 29. Steps when retrofitting equipment

Connectivity

While developing a brownfield site does not necessarily limit a manufacturer's ability to leverage advantages related to value and supply chain connectivity, building a greenfield site provides comparatively more freedom in the choice of location, enabling increased flexibility to benefit and capitalize on connectivity.

Summary

Building out brownfield facilities is shown to be a preferable option in almost all cases because of the substantial CAPEX and lead time savings, provided that common utilities for manufacturing purposes are available. Early-stage fermentation-derived product companies are more likely to consider retrofitting equipment as they have a greater need to bootstrap operations due to resource constraints. Since blueprints for retrofitting fermentation equipment are not yet available on the market, having access to the required skills and expertise in-house plays a crucial role in making the retrofit option viable. The next section presents an overview of the parallel industries that prove to be most favorable for building brownfield facilities and retrofitting idle equipment.

2.3 Relevant parallel industries for brownfield development & retrofits

Success cases from several of the companies interviewed for this report show that leveraging existing infrastructure and equipment from parallel industries can be an economical, time-effective, and technically feasible strategy for scaling capacity of fermentation-derived products, particularly for liquid biomass processes (Figure 30). Drawing on expert interviews and retrofitting case studies, this section analyzes seven parallel industries that utilize fermentation or related processes to produce both food and non-food products.

In assessing the potential retrofit viability of the seven industries under consideration, this report considers two broad criteria: 1) process-related opportunities and 2) availability considerations. By taking these factors together, we can evaluate the feasibility of retrofitting each industry and identify where the most promising opportunities are. We define these criteria as follows:

Process-related opportunities:

Upstream and downstream process similarity for protein fermentation (including the applied manufacturing standards), retrofit complexity in terms of equipment compatibility, and industry-wide site characteristics such as proximity to suppliers and customers, utilities, logistics, and co-location.

Availability considerations:

Opportunities to secure a facility or equipment for retrofit, considering:

- **Margins:** indicating how likely a target is to convert their operations to produce fermentation-derived products.
- **Market dynamics:** overview and prognoses of growth or decline in that parallel industry, indicating how likely it is to find a decommissioned site or equipment, along with general qualitative market considerations.

It is important to note that, while some parallel industries would be favorable for retrofitting based on the first criterion (process-related opportunities), the high profit margins they achieve with current operations (availability considerations) preclude them from being viable options. The relatively low margins generally achieved in the food processing industry (~5.16%),[12] as well as those expected among fermentation-derived product companies, do not translate into an attractive business case for high-margin parallel industries. Among the ones assessed here, those considered viable generate profit margins below 10 percent and those considered non-viable generate profit margins above 25 percent.

	Breweries	Ethanol plants	Wineries	Flavor houses	Enzymes	Pharma	Citric & Malic Acid
Overall	●	●	●	🟡	🟡	🟡	🟡
Process-related	🟡	🟡	🟡	●	●	●	●
Availability	●	●	●	🔵	🔵	🔵	🔵

Opportunity level
● High
🟡 Medium
🔵 Low

Figure 30. Parallel industry opportunity assessment

While our analysis shows that taking advantage of existing equipment and sites can be suitable for biomass fermentation, experts identify less opportunity for precision fermentation. We identified no exemplary retrofit case, and industry experts underlined concerns related to the loss in titers or yield loss as well as the significant cost involved. As such, this parallel-industries assessment mainly focuses on opportunities for retrofitting equipment for biomass fermentation, specifically liquid state.

Of the seven industries considered, three are especially promising based on our criteria. For reference, we also include a brief assessment of the four parallel industries that currently remain non-viable due to availability considerations.

Though this assessment offers a broad perspective on the viability of the seven industries under consideration, it is important to note that each retrofit project is unique. Thus, there may be other more or less feasible cases within each industry to consider. Further, varying accessibility of different industries in different geographic regions can influence the feasibility and decision to retrofit facilities from parallel industries.

Equipment-related opportunities

As fermenters and bioreactors are core equipment for producing fermentation-derived protein, viability assessments predominately focus on these.

Upstream features: Experts point to several functionality requirements as essential for any secondhand fermenter or bioreactor to possess:

- Automated temperature control and cooling system
- Oxygen supply & agitation with an impeller as well as bubble functionality
- Pressurizing and de-pressurizing controls

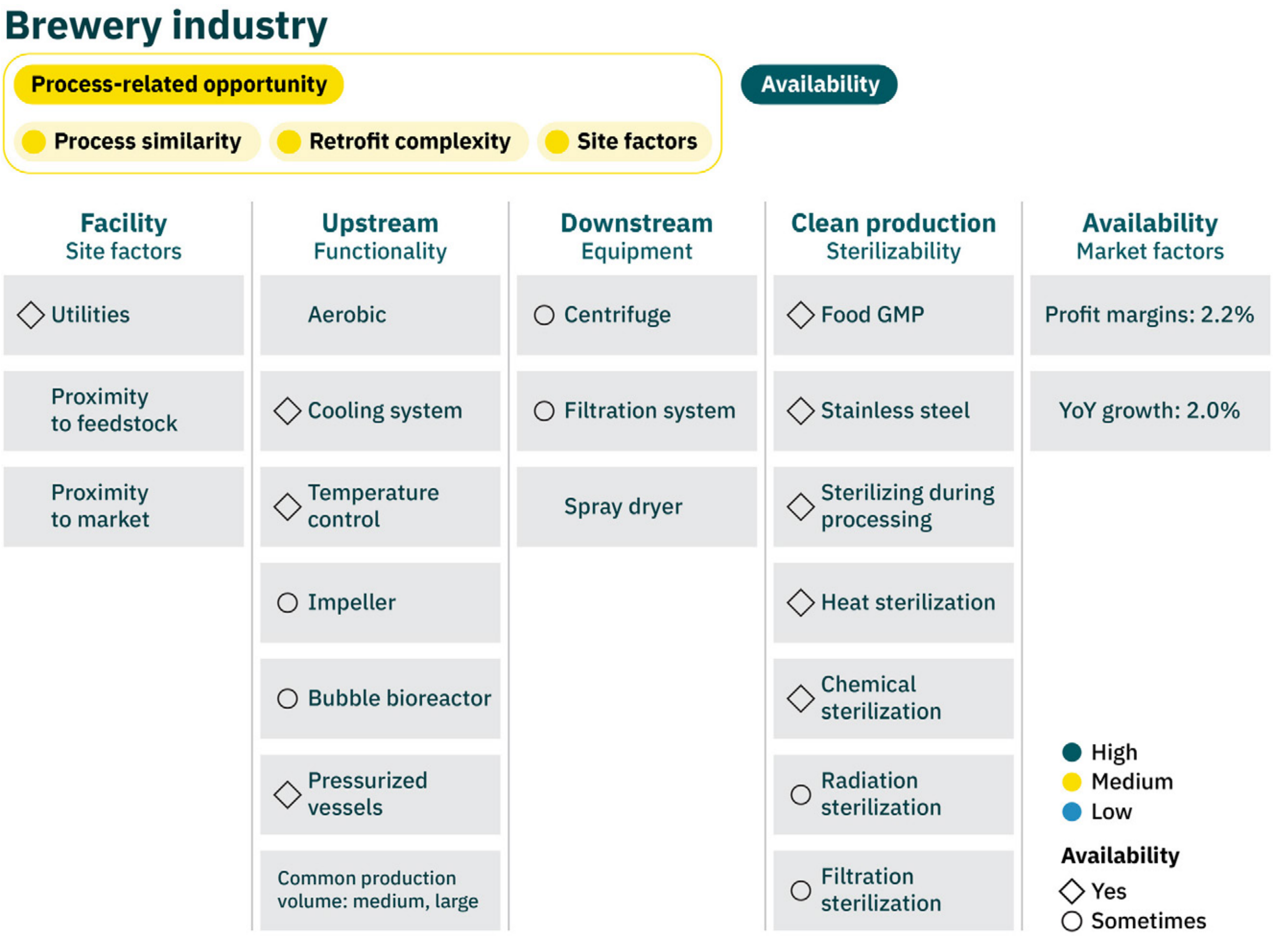
Downstream equipment: can also be considered in the overall feasibility calculation. The most common equipment includes:

- Filtration systems
- Centrifuges
- Spray dryers

High-potential parallel industries

Breweries

Contributors have identified the beer brewing industry as one of the most promising parallel industries (Figure 31). It offers widespread availability of idled and decommissioned equipment and facilities due to market dynamics, some process-related similarities among fermenter equipment, and low profit margins (2.2%[13]) that could translate into a viable business case for retrofitting. The biomass fermentation experts interviewed express the highest level of optimism in capitalizing on current market dynamics to leverage existing brewery infrastructure for fermentation-derived production. Large-scale multinational breweries directing interest toward leveraging their assets and expertise to build out fermentation capacity for food production highlight the potential of this industry. For example, drawing on large-scale brewing experience, AB InBev, entered a partnership with The EVERY Company (formerly Clara Foods) in 2021 to explore options to develop solutions to scale up food fermentation and downstream processes.[14]



Brewery industry

Process-related opportunity

● **Process similarity** ● **Retrofit complexity** ● **Site factors**

Availability

Facility Site factors	**Upstream** Functionality	**Downstream** Equipment	**Clean production** Sterilizability	**Availability** Market factors
◇ Utilities	Aerobic	○ Centrifuge	◇ Food GMP	Profit margins: 2.2%
Proximity to feedstock	◇ Cooling system	○ Filtration system	◇ Stainless steel	YoY growth: 2.0%
Proximity to market	◇ Temperature control	Spray dryer	◇ Sterilizing during processing	
	○ Impeller		◇ Heat sterilization	
	○ Bubble bioreactor		◇ Chemical sterilization	
	◇ Pressurized vessels		○ Radiation sterilization	
	Common production volume: medium, large		○ Filtration sterilization	

● High
● Medium
● Low

Availability
◇ Yes
○ Sometimes

Figure 31. Breweries overview

Process-related opportunities: Medium

Process similarity: Medium. Breweries boast some common fermenter features as well as food good manufacturing practices (GMP) that ensure sterilizability.[15]

Retrofit complexity: Medium

Upstream: Fermenters would need to be adapted to allow for aerobic fermentation processes. There is ambiguity surrounding the ease of this conversion, as aerobic fermenters are commonly equipped with air or pure oxygen aeration systems and vigorous agitation components for maintaining a high oxygen transfer rate (OTR), and to prevent cell settling. While the retrofitting of brewery fermenters is still subject to further research and blueprints are yet to be determined, biomass experts express optimism.

Downstream: While there can be an overlap between liquid biomass downstream processing and common brewery downstream processing related to using centrifuges and filtration systems to remove solids from the clear liquid, there are limited opportunities to retrofit and those are not generalizable. Experts emphasize that downstream processing is unique to each application, making complete equipment replacements unlikely.

Site factors: Medium. Breweries commonly possess relevant, well-connected infrastructure such as warehousing facilities, transportation equipment, and access to roads and railways for the import and export of goods. However, most breweries do not strategically prioritize co-location with feedstock.

Availability considerations: High

Margins: Low margins (2.2%) compared to other parallel industries make breweries strong contenders for potential retrofits. One fermentation company interviewed was exploring the possibility of utilizing idled brewing capacity to offer breweries alternative revenue streams.

Market dynamics: Slow overall year-over-year growth of 2 percent in the U.S. and a high level of recent market consolidation among a few large players have freed capacity, particularly among smaller and medium-sized breweries.[16] In total, 9,247 breweries operated across the U.S. in 2021, with a high concentration in the Midwest. In that same year, the industry saw a high level of brewery turnover, with 646 new breweries opening and 178 closing.[17]

Ethanol facilities

Our experts identified the ethanol industry as a promising parallel industry due to facility co-location with relatively inexpensive feedstocks (e.g., corn, sugarcane, and sugar beets)[18] and existing supply chain infrastructure. However, as fuel ethanol production involves less complex fermentation processes than for food and operates at industrial rather than food-grade standards, greater effort is needed to retrofit equipment and achieve food-grade GMP (see Figure 32 for additional insight).

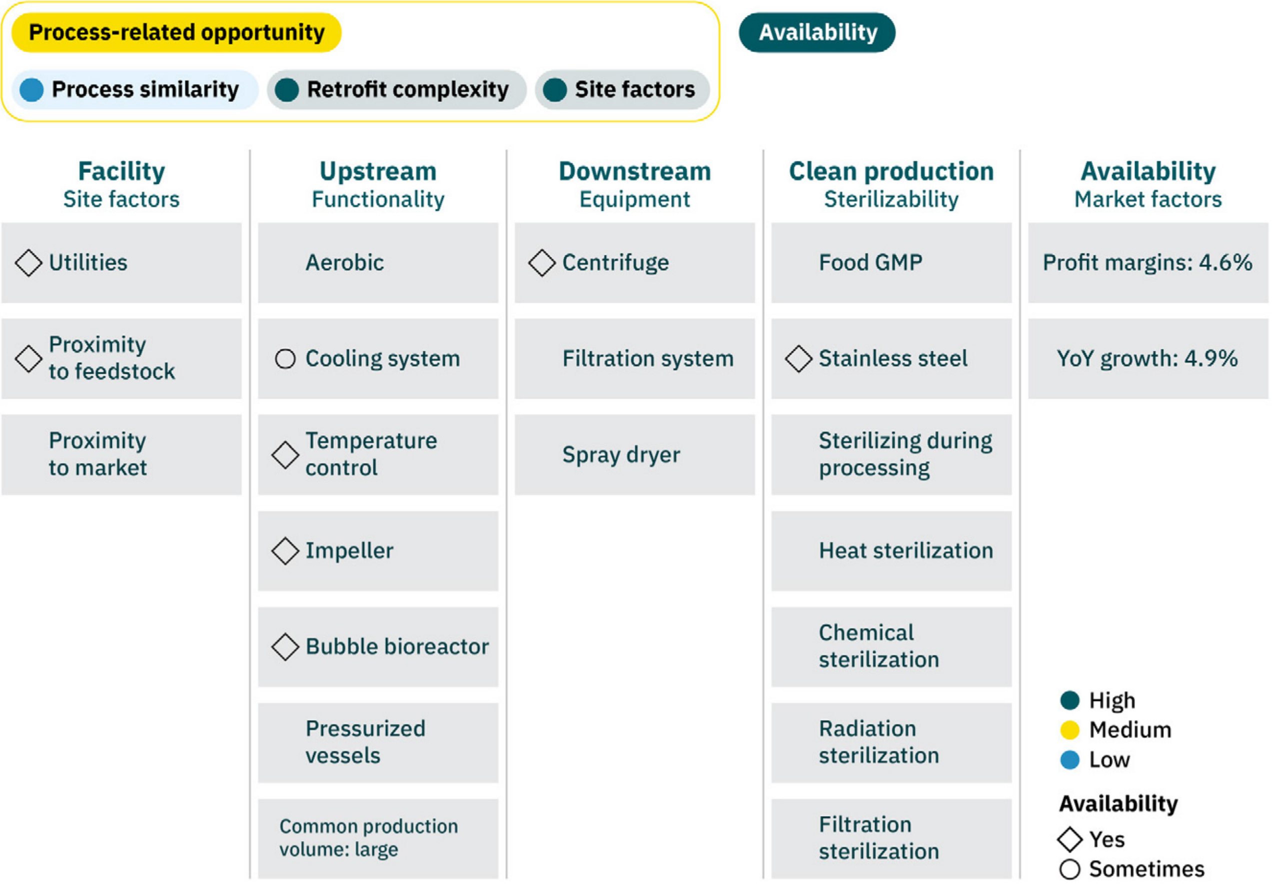
Process-related opportunities: Medium

Process similarity: Low. While ethanol fermenters are based on industrial rather than food GMP, using stainless-steel fermenters can allow for clean batch production and sterilizability, which is required for food production. However, industrial processes are often subject to contamination as companies do not typically sterilize feedstocks. Following industrial GMP, producers commonly add antibiotics and rely on the hostile environment created by acidification in ethanol production to address this contamination. Distillation is the main processing for isolating ethanol itself, a downstream process that has no overlap with protein purification.

Retrofit complexity: High

Upstream: Ethanol fermentation processes have relatively simple requirements because the microorganisms employed are less sensitive to

Ethanol facilities



Process-related opportunity

● Process similarity ● Retrofit complexity ● Site factors

Availability

Facility Site factors	Upstream Functionality	Downstream Equipment	Clean production Sterilizability	Availability Market factors
◇ Utilities	Aerobic	◇ Centrifuge	Food GMP	Profit margins: 4.6%
◇ Proximity to feedstock	○ Cooling system	Filtration system	◇ Stainless steel	YoY growth: 4.9%
Proximity to market	◇ Temperature control	Spray dryer	Sterilizing during processing	
	◇ Impeller		Heat sterilization	
	◇ Bubble bioreactor		Chemical sterilization	
	Pressurized vessels		Radiation sterilization	
	Common production volume: large		Filtration sterilization	

● High
● Medium
● Low

Availability
◇ Yes
○ Sometimes

Figure 32. Ethanol facilities overview

environmental conditions such as heat and low pH values compared to fermentation-derived food manufacturing. Adapting fermenters from industrial to food GMP would require more extensive modifications to enable clean batch and aerobic fermentation. This would involve process adjustments to provide sufficient aeration and OTR including automation features to better control the fermentation environment (temperature and pH values) to prevent contamination and optimize metabolic processes. Facilities are not necessarily designed to prevent contamination as ethanol itself keeps the equipment sterile. Uncertainty exists among experts surrounding the viability of implementing these adaptations.

Downstream: Some overlap could exist between liquid biomass and ethanol downstream processing related to the use of centrifuges and distillation columns to separate solids from fermented broth and other impurities. However, experts claim that opportunities to retrofit are limited and cannot be generalized, emphasizing that downstream processing is unique to each application, making complete equipment replacements unlikely.

Site factors: High. Ethanol facilities are commonly co-located with sources of feedstock such as cornstarch-based dextrose. The development of prior ethanol brownfield facilities provides an opportunity for fermentation-derived product manufacturing to leverage co-location benefits such as reduced supply-chain risk, lower storage and transport costs, and feedstock pre-treatment. Ethanol facilities in the U.S. tend to co-locate with (or internally house) corn mills for direct access to cornstarch-based dextrose, currently the least expensive source of carbon feedstock for fermentation processes.[19] Over 90 percent (178) of these facilities are located in the U.S. Midwest (the "Cornbelt"), presenting fermentation-derived protein companies with potential access to direct feedstock sources through brownfield development.[20]

Availability Considerations: High

Margin: Low. Year-over-year profit margins (4.6%) in this industry make the possibility of retrofitting capacity potentially cost-effective.[21]

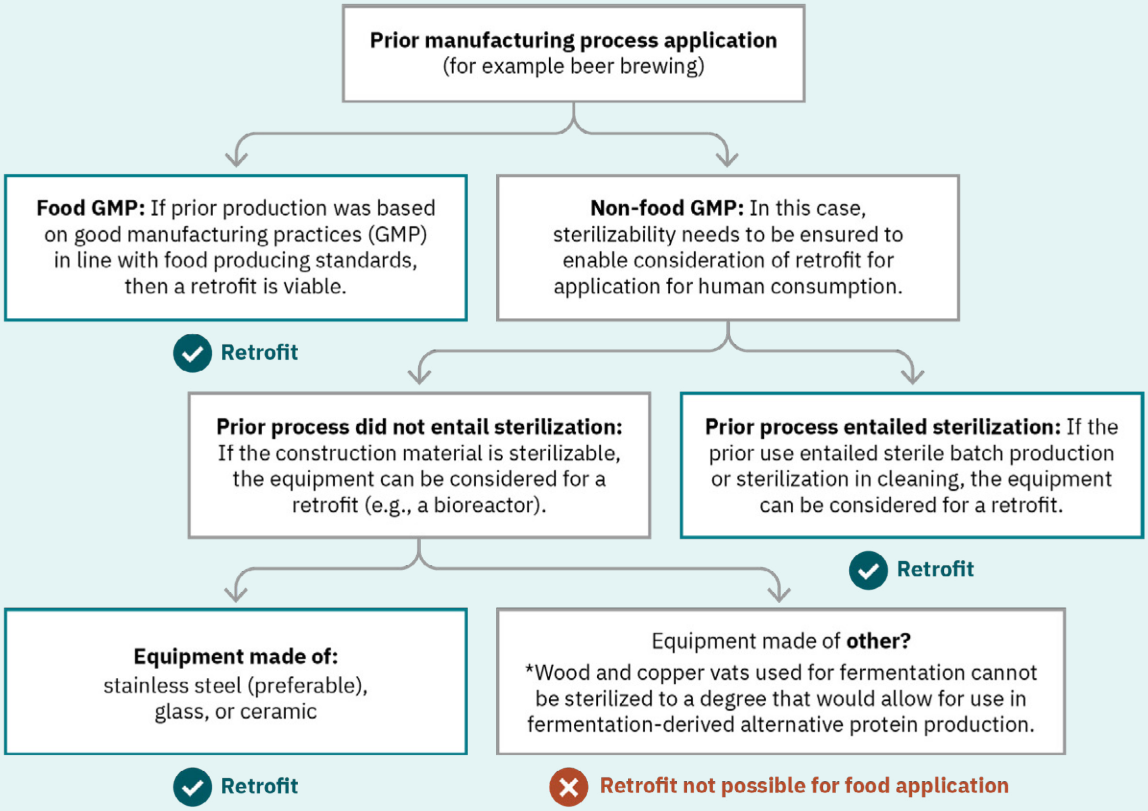
Market dynamics: The ethanol industry is sensitive to market fluctuations in fuel and corn prices and shifting government regulations, such as renewable fuel standards (RFS), which have an impact on available or convertible capacity.[22] Lower feedstock prices or stricter RFS mandates can, for example, drive up demand for ethanol while, in the long term, the growth of electric vehicles could make this a declining market with available facilities and equipment for brownfield development and retrofitting.

Cleanability and Sterilizability

The potential to retrofit parallel industry equipment is influenced by two main technical factors: cleanability and functionality. This report specifically considers bioreactors, which are a core element for fermentation-derived protein manufacturing with a significant CAPEX component, and the main piece of equipment that experts focused on throughout our interviews.

Cleanability

Can the equipment be cleaned and completely sanitized to meet food-safety requirements? This represents an initial go/no-go factor for the assessment.



Sterilization

The seven parallel industries utilize stainless steel in their fermentation processes–the preferred material for use in food production as it provides the best sterilization capacities. However, potential for equipment contamination may need to be verified, excluding certain industries.

Despite using industrial rather than food GMP norms, the use of stainless steel in equipment for pharmaceuticals, animal feed, citric and malic acids, and ethanol makes retrofit possible. Depending on the desired end-product, the sterilization process applicable can vary.

	Breweries	Ethanol plants	Wineries	Flavor houses	Amino acid & enzymes	Pharma	Citric & malic acid
Sterilizable	✓	✓	✓	✓	✓	✓	✓
Sterilization in production	✓		✓	✓	✓	✓	✓
Heat sterilization	✓		✓	✓	✓	✓	✓
Chemical sterilization	✓		✓	✓	✓	✓	✓
Radiation sterilization	✓		✓			✓	
Filtration sterilization	✓		✓		✓		

Wineries

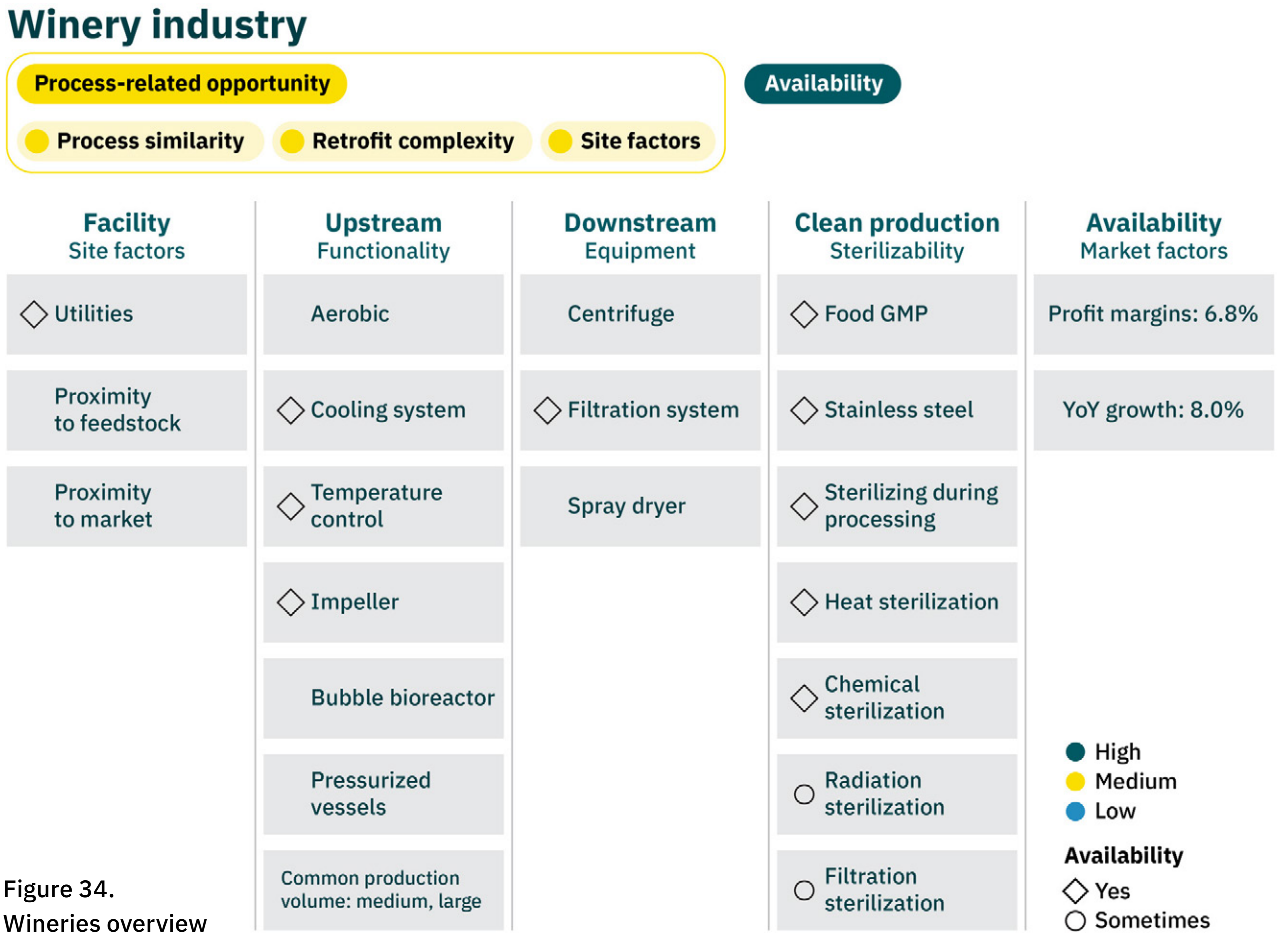
The wine industry is a promising parallel industry with significant downtime in equipment use due to the seasonality of wine production. Moreover, there are some process similarities in terms of equipment and production standards that comply with food GMP. Leveraging winery equipment for producing alternative proteins could be especially interesting in the "New World" of wine, as winemakers commonly use stainless-steel fermenters in the U.S., South Africa, and Australia (unlike in Europe).[23] Experts have expressed optimism in the viability of adapting anaerobic fermenters used for winemaking to the required aerobic processes; however, the specifics of this conversion require additional research.

Process-related opportunities: Medium

Process similarity: Medium. This industry uses food-grade GMP and stainless-steel fermenters (in the U.S., South Africa, and Australia) as well as some common fermenter features (see Figure 34).

Retrofit complexity: Medium to High

Upstream: Using winery equipment may require certain modifications from anaerobic to aerobic fermentation processing, but experts can look for potential technical overlaps that would reduce the need for modification. While wine fermentation is primarily an anaerobic process, certain winemakers choose to introduce oxygen at early process stages to build yeast populations or for micro-oxygenation at later stages to develop



Winery industry

Process-related opportunity: 🟡 Process similarity · 🟡 Retrofit complexity · 🟡 Site factors

Availability ●

Facility Site factors	Upstream Functionality	Downstream Equipment	Clean production Sterilizability	Availability Market factors
◇ Utilities	Aerobic	Centrifuge	◇ Food GMP	Profit margins: 6.8%
Proximity to feedstock	◇ Cooling system	◇ Filtration system	◇ Stainless steel	YoY growth: 8.0%
Proximity to market	◇ Temperature control	Spray dryer	◇ Sterilizing during processing	
	◇ Impeller		◇ Heat sterilization	
	Bubble bioreactor		◇ Chemical sterilization	
	Pressurized vessels		○ Radiation sterilization	
	Common production volume: medium, large		○ Filtration sterilization	

● High
🟡 Medium
🔵 Low

Availability
◇ Yes
○ Sometimes

Figure 34.
Wineries overview

certain flavors. Wineries use mechanical stirrers or agitators as well as pneumatic agitation to ensure the wine is evenly mixed. Nonetheless, winemaking requires significantly lower OTR than the production of fermentation-derived proteins as excessive oxygen exposure can negatively impact wine quality. Finally, the lack of automated controls in the wine fermenters suggests a higher level of manual effort involved in retrofitting or running biomass fermentation processes. Considering this industry has received little attention for potential retrofit so far, the ease of retrofitting remains uncertain and requires further research to validate the hypothesis that suggests potential ease of retrofitting.

Downstream: The relatively straightforward nature of wine packaging also means that there is a general lack of DSP equipment in wineries compared to fermentation-derived product manufacturing facilities. While DSP for wine production can include filtration systems to remove impurities from the wine, opportunities to retrofit those filters are limited and cannot be generalized, creating an investment need for additional equipment when utilizing winery facilities during downtime.

Site factors: Medium. No significant negative factors have been identified other than the fact that the geographic distribution of wineries is limited to specific regions. Like breweries, wineries require well-connected infrastructure to enable the import, export, and storage of goods.

Availability Considerations: High

Margins: As margins are relatively high (at around 5.85%[24] year over year) and revenue continues to grow, a business case would need to be made for utilizing capacity during seasonal downtime. Considerable research and development would be needed to understand the correct hybrid production that allows for high-quality and sufficient volume production for both protein and beverage products from the same fermentation vessels and systems.

Market dynamics: With a projected global market growth of 8 percent year over year from 2021 until 2026 and stable margins, wineries may not be readily available for acquisition.[25] However, since the wine industry is seasonal, there may be periods of the year (up to three-quarters) when wineries have excess capacity. Considering the increasingly competitive nature of the global wine market is driven by increased wine production due to more countries starting production, the New World wineries are likely to look for income stream diversification, which suggests a potential willingness to retrofit their facilities to produce fermentation-based proteins during the off-season. How dual-use or partially retrofit facilities may work to produce both products, however, remains to be seen.

In total, there are 11,053 wineries in the U.S. as of 2021, providing an interesting business opportunity in terms of potential capacity for retrofit.[26] While California produces 85 percent of U.S. wine, 2 percent of wine is produced in Michigan and Ohio, which would be more favorable targets for retrofitting as they are located in the U.S. Cornbelt, providing abundant sources of corn-based dextrose feedstock.

Low-potential parallel industries

While the remaining parallel industries would be favorable for brownfield development and retrofitting based on process-related opportunities, the high profit margins they achieve with current operations preclude them from being viable options. Increasing growth projections and steady demand also contribute to the view that these industries have a low potential for providing available capacity in the near future. Additionally, though we considered the animal feed industry, we do not include it in this list due to the lack of information related to retrofit and availability potential.

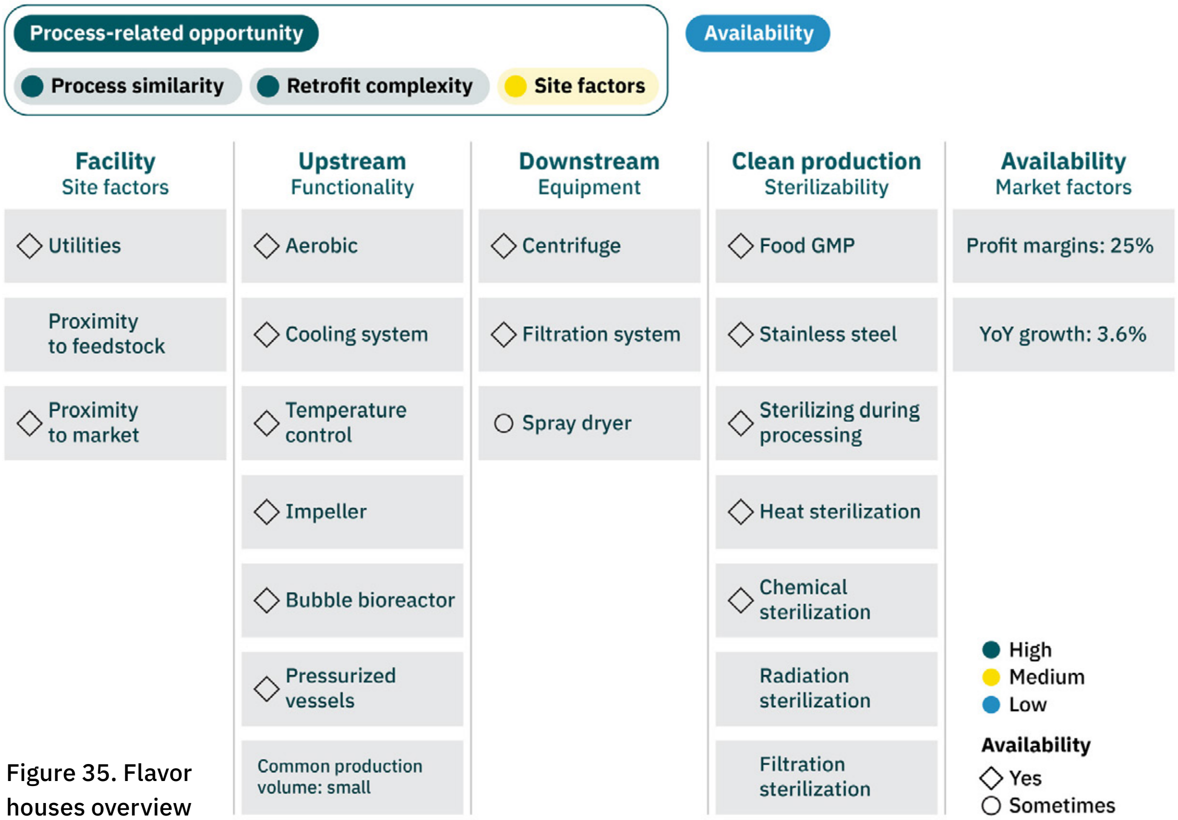
Flavor houses

Flavor houses are increasingly turning to fermentation to produce flavor and aroma compounds used widely in food. These facilities boast a high level of upstream process similarity, have some DSP overlap, and apply food GMP. However, experts point out that the high margins in this industry do not offer a business case for conversions. At the same time, positive industry growth makes the likelihood of decommissioned equipment becoming available in the foreseeable future low. Industry experts noted that only a small portion of their production involves fermentation, suggesting that overall fermentation volumes are low (Figure 35).

Enzyme producers

Many enzymes used in food and nutrition markets are fermented products. Enzyme producers exhibit the highest degree of process similarity to fermentation-derived product production (with aerobic processes with pressurization) and apply food GMP. Downstream processing for enzymes involves isolating and purifying protein products, providing excellent overlap with precision fermentation for food protein. However, the industry's high margins and upward growth trend make the possibility of conversions or acquiring decommissioned equipment unlikely for the foreseeable future. Another future possibility is the potential to engineer or bioprospect "dual use" strains that produce sufficient quantities of commercial enzymes with the biomass serving as a source of biomass protein to be processed in a separate stream (Figure 36).

Flavor houses



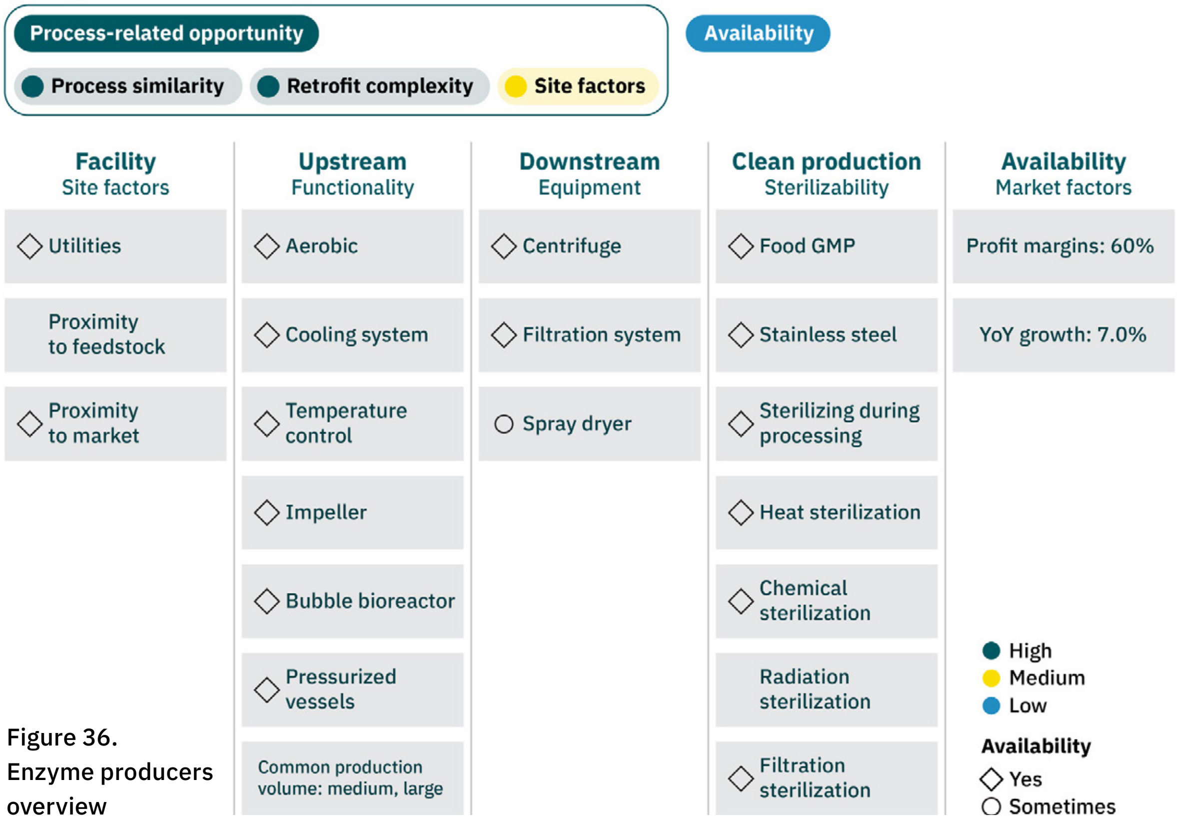
Facility Site factors	Upstream Functionality	Downstream Equipment	Clean production Sterilizability	Availability Market factors
◇ Utilities	◇ Aerobic	◇ Centrifuge	◇ Food GMP	Profit margins: 25%
Proximity to feedstock	◇ Cooling system	◇ Filtration system	◇ Stainless steel	YoY growth: 3.6%
◇ Proximity to market	◇ Temperature control	○ Spray dryer	◇ Sterilizing during processing	
	◇ Impeller		◇ Heat sterilization	
	◇ Bubble bioreactor		◇ Chemical sterilization	
	◇ Pressurized vessels		Radiation sterilization	
	Common production volume: small		Filtration sterilization	

● High
● Medium
● Low

Availability
◇ Yes
○ Sometimes

Figure 35. Flavor houses overview

Enzymes industry



Facility Site factors	Upstream Functionality	Downstream Equipment	Clean production Sterilizability	Availability Market factors
◇ Utilities	◇ Aerobic	◇ Centrifuge	◇ Food GMP	Profit margins: 60%
Proximity to feedstock	◇ Cooling system	◇ Filtration system	◇ Stainless steel	YoY growth: 7.0%
◇ Proximity to market	◇ Temperature control	○ Spray dryer	◇ Sterilizing during processing	
	◇ Impeller		◇ Heat sterilization	
	◇ Bubble bioreactor		◇ Chemical sterilization	
	◇ Pressurized vessels		Radiation sterilization	
	Common production volume: medium, large		◇ Filtration sterilization	

● High
● Medium
● Low

Availability
◇ Yes
○ Sometimes

Figure 36. Enzyme producers overview

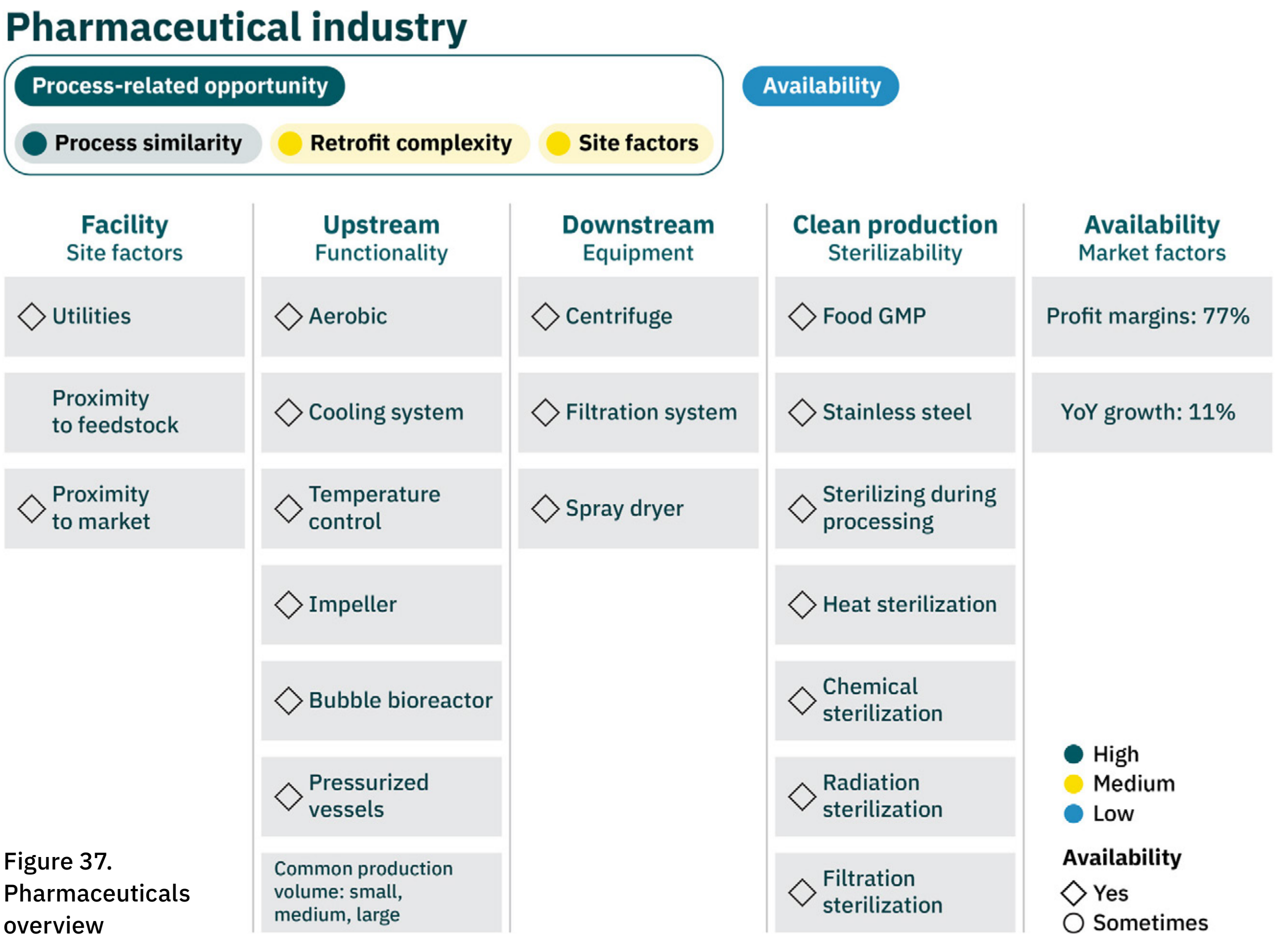
Pharmaceuticals

The involved systems and processing equipment involved in pharmaceutical production processes are high quality and have many desirable features for fermentation-derived production, such as vessel pressurization and efficient liquid handling systems. However, these facilities are designed on pharmaceutical GMP, and end-products are commonly produced at lower quantities than the volumes needed to drive down the cost of food production. Additionally, the upstream and downstream processes include sensitive control systems demanding more operator supervision and input compared to fermentation-derived production, increasing OPEX (Figure 37).

High margins and positive market development point to limited equipment availability. Experts also point out that maintaining pharmaceutical GMP subjects the involved equipment to harsh conditions such as high temperatures, corrosive chemicals, and abrasive materials, leading to deterioration over time. As this high-specification equipment represents high upfront CAPEX, companies are likely to utilize it for the entire lifecycle and decommission once it is no longer usable.

Citric and malic acid

Producing organic acids at an industrial scale is an excellent example of a fermentation-derived product that can be made economically and in large quantities using biotechnology. Citric and malic acid production plants boast a medium level of process similarity, including the use of sterilizable stainless-steel fermentation vessels. Site benefits include proximity to feedstock and industrial customers, allowing for shared infrastructure. However, producers operate based on industry GMP, and the extraction, DSP, and purification of organic acids are different than for protein isolation and processing. Citric and malic



Pharmaceutical industry

Process-related opportunity

● **Process similarity** ● **Retrofit complexity** ● **Site factors**

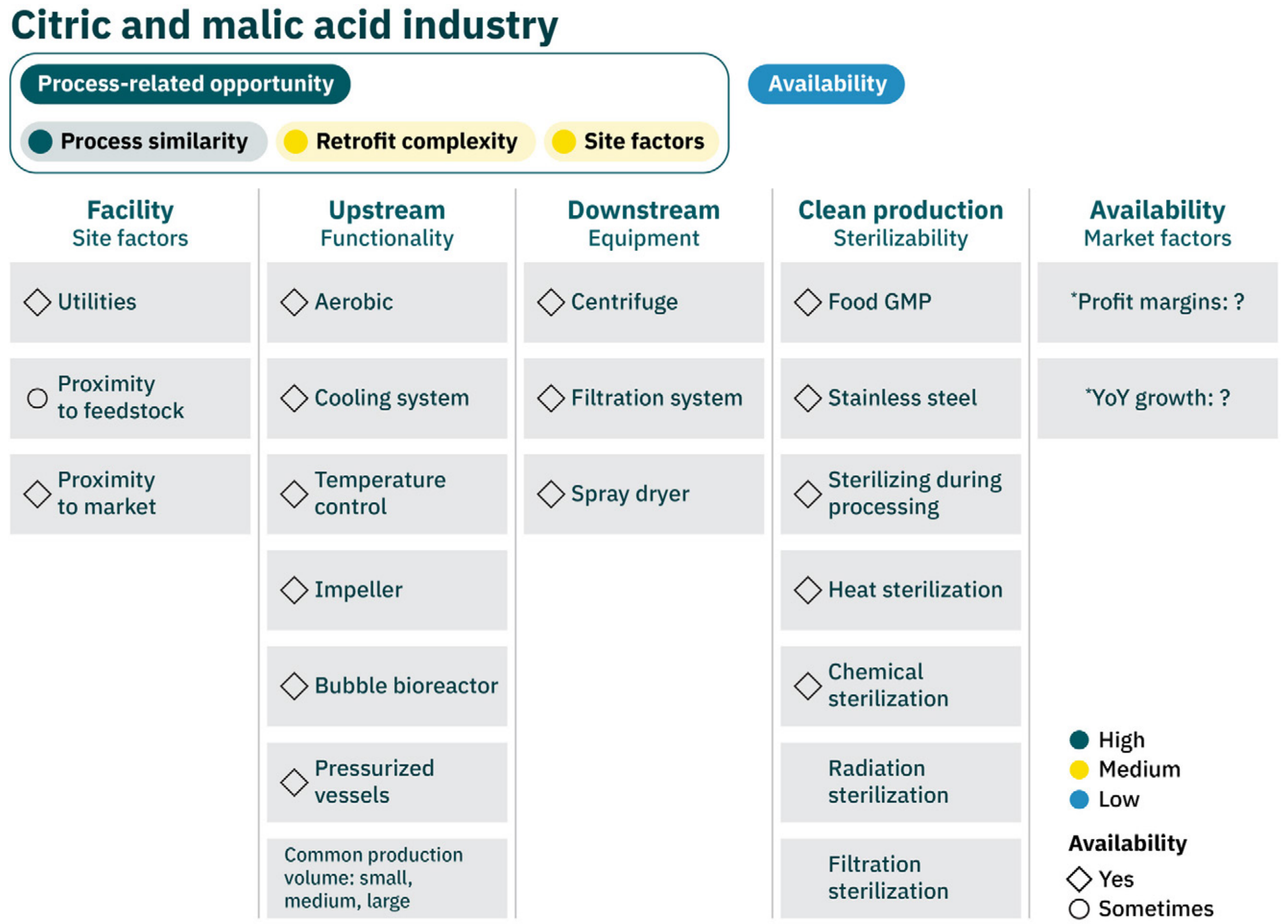
Availability

Facility Site factors	**Upstream** Functionality	**Downstream** Equipment	**Clean production** Sterilizability	**Availability** Market factors
◇ Utilities	◇ Aerobic	◇ Centrifuge	◇ Food GMP	Profit margins: 77%
Proximity to feedstock	◇ Cooling system	◇ Filtration system	◇ Stainless steel	YoY growth: 11%
◇ Proximity to market	◇ Temperature control	◇ Spray dryer	◇ Sterilizing during processing	
	◇ Impeller		◇ Heat sterilization	
	◇ Bubble bioreactor		◇ Chemical sterilization	
	◇ Pressurized vessels		◇ Radiation sterilization	
	Common production volume: small, medium, large		◇ Filtration sterilization	

● High
● Medium
● Low

Availability
◇ Yes
○ Sometimes

Figure 37. Pharmaceuticals overview



Citric and malic acid industry

Facility Site factors	Upstream Functionality	Downstream Equipment	Clean production Sterilizability	Availability Market factors
◇ Utilities	◇ Aerobic	◇ Centrifuge	◇ Food GMP	*Profit margins: ?
○ Proximity to feedstock	◇ Cooling system	◇ Filtration system	◇ Stainless steel	*YoY growth: ?
◇ Proximity to market	◇ Temperature control	◇ Spray dryer	◇ Sterilizing during processing	
	◇ Impeller		◇ Heat sterilization	
	◇ Bubble bioreactor		◇ Chemical sterilization	
	◇ Pressurized vessels		Radiation sterilization	
	Common production volume: small, medium, large		Filtration sterilization	

● High
● Medium
● Low

Availability
◇ Yes
○ Sometimes

*Publicly available data is not available for the Availability Opportunity Indicators.
Considering this industry is low-volume, high-value, we presume the Available Opportunity is Low.

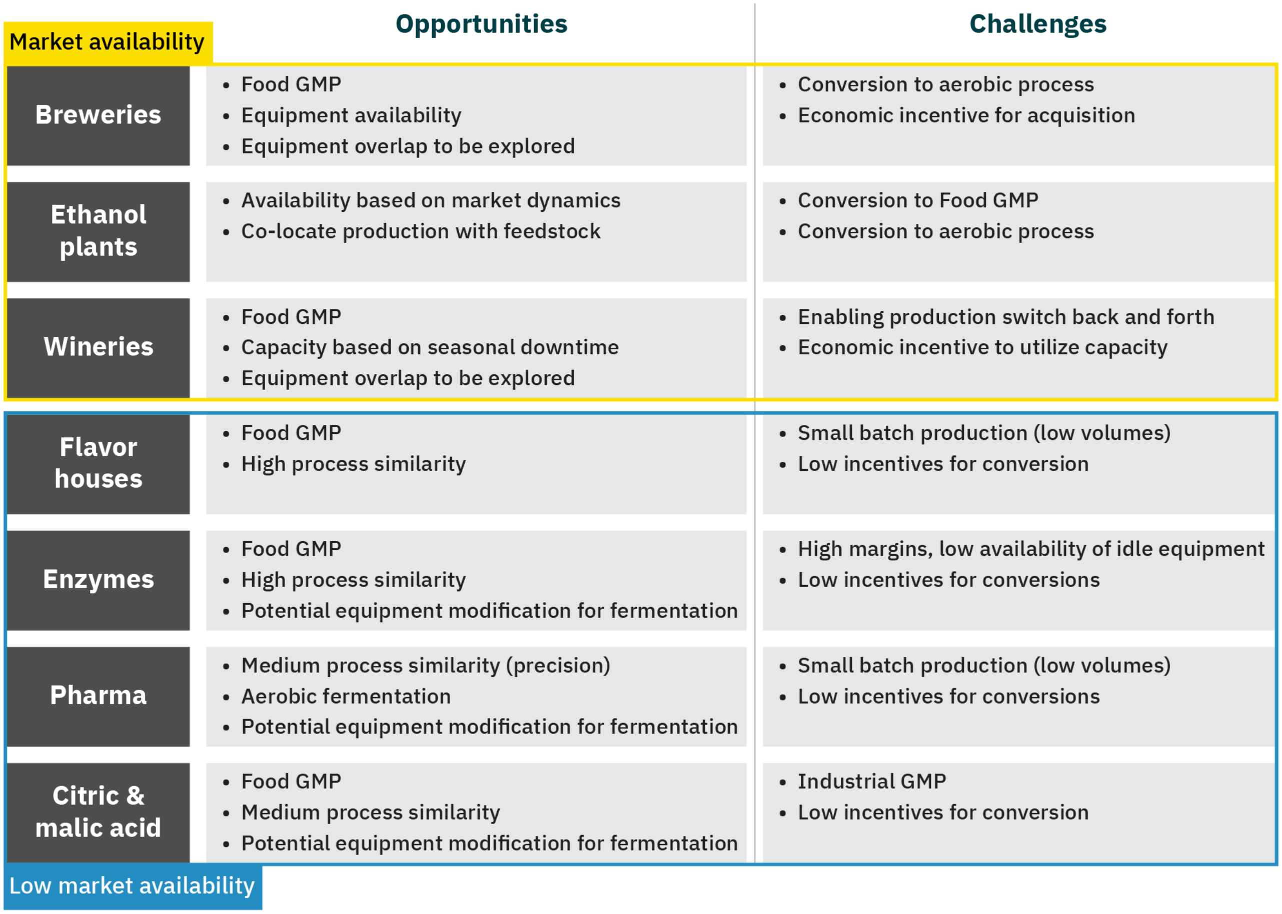
Figure 38. Citric and malic acid overview

acids are commercially important organic acids with extensive use in food and a variety of other industries, making it unlikely that these facilities will be available considering the high margins achieved. Nevertheless, industry experts see potential in leveraging this industry's infrastructure for retrofitting (Figure 38).

Summary

Despite limitations in the use of facilities across these seven industries, opportunities do exist, and brownfield development and retrofitting have proven to be technically and economically feasible options for expanding fermentation capacity. The three industries highlighted with high potential for brownfield development and equipment retrofitting show favorable process-related opportunities and market availability. Though the other four industries do present certain advantages (Figure 39), limitations on market availability make them less viable candidates.

The decision to utilize brownfield developments and retrofit equipment to develop manufacturing capabilities needs to be evaluated on a case-by-case basis. Companies looking for more accessible opportunities are likely to find more success by targeting facilities and equipment from these three prioritized industries. Figure 39 summarizes the key opportunities and challenges of brownfield development and equipment retrofitting for each parallel industry.



Market availability

	Opportunities	Challenges
Breweries	• Food GMP • Equipment availability • Equipment overlap to be explored	• Conversion to aerobic process • Economic incentive for acquisition
Ethanol plants	• Availability based on market dynamics • Co-locate production with feedstock	• Conversion to Food GMP • Conversion to aerobic process
Wineries	• Food GMP • Capacity based on seasonal downtime • Equipment overlap to be explored	• Enabling production switch back and forth • Economic incentive to utilize capacity
Flavor houses	• Food GMP • High process similarity	• Small batch production (low volumes) • Low incentives for conversion
Enzymes	• Food GMP • High process similarity • Potential equipment modification for fermentation	• High margins, low availability of idle equipment • Low incentives for conversions
Pharma	• Medium process similarity (precision) • Aerobic fermentation • Potential equipment modification for fermentation	• Small batch production (low volumes) • Low incentives for conversions
Citric & malic acid	• Food GMP • Medium process similarity • Potential equipment modification for fermentation	• Industrial GMP • Low incentives for conversion

Low market availability

Figure 39. Summary of parallel industry evaluation

Conclusion

Our analysis of the current manufacturing capacity landscape for fermentation-derived protein products shows that companies will need to make significant efforts to advance this industry. However, pathways do exist for efficiently increasing fermentation capacity, scaling up the production of fermentation-derived products, and minimizing supply chain bottlenecks. There are a few key takeaways that players in this space should keep in mind:

Global fermentation-derived product manufacturing capacity is estimated at ~16 million liters, split between producers (7.5 million liters) and food-exclusive CMOs (8.2 million liters).

This capacity has the potential to produce 0.4–2.8 million metric tons of alternative protein food product, which is equivalent to the 2022 global consumption of alternative meat and seafood.[27] This suggests that simple volumetric capacity is not a limiting factor; rather, there is a mismatch of current manufacturing capacity in terms of scale, technical capabilities, and the geographic distribution of production capacity compared to the demand, and local needs of the players in this nascent industry.

Limited technical capabilities and capacity at lab and demo scale are bottlenecks for scaling up.

Companies in the early stages of development face resource constraints and high investment risk for their technologies, so they primarily rely on lab- and demo-scale public research facilities and CMOs to access process equipment as well as technical know-how for scaling up production. Only 4 percent of current capacity is at lab and demo scale, with industry interviews indicating that the majority of fermentation-derived product companies are seeking capacity at these scales. Pilot and demonstration scales present an opportunity for research and training at universities and institutional facilities while servicing commercial clients.

Capacity is predominantly concentrated in Europe (47%) and the U.S. (34%).

There is a notable lack of dedicated food-grade commercial manufacturing facilities in Africa, Latin America, and Asia Pacific.

CMOs will play a key role in accelerating the industry.

This is especially true for the short-to-mid term until expanded in-house manufacturing capacity improves cost structures at commercial scale. CMOs: 1) enable early-stage companies to scale up production by providing process flexibility, key skills, expertise, and opportunities to reduce upfront CAPEX investments; 2) provide an economically viable option for companies entering this market, especially in helping them through the valley of death; and 3) are vital until marginal production costs lead to an inflection point at which building proprietary facilities becomes economically favorable.

Retrofitting used equipment can be economical and technically feasible.

Companies can leverage this option to reduce CAPEX (by as much as 90%) and lead times when developing in-house manufacturing capability. Successful retrofitting is dependent on having the right expertise to identify suitable opportunities and to adapt and operate retrofitted equipment. Breweries, wineries, and ethanol facilities are the most suitable options for retrofitting, given process similarity and market conditions. Retrofitting is currently most relevant for liquid-state biomass fermentation.

The most suitable manufacturing pathway will vary from company to company.

The involved decision-making factors are also dynamic, meaning companies should frequently evaluate their manufacturing needs and make calculated decisions at different levels of maturity.

Additional capacity may be added through improved bioprocessing and technological innovation.

Companies may focus on adding additional biotechnology to increase the productivity, yield, and titer of fermentation-derived products through improved organism growth, protein expression, fermentation conditions, and/or separations technology. Therefore, the investor focus seems to have shifted toward so-called enabling technologies as advances in any of these categories will allow for more production without physical expansion of facilities.

Fermentation-derived products have the potential to carve out a major share of the consumer market as well as stimulate growth in other alternative protein categories by providing functional ingredients. Investment in fermentation-derived product manufacturing presents companies and investors with an opportunity to capture a share of an emerging industry with a commercially lucrative and sustainable future.

Methodology

Section 1: Fermentation-derived product capacity landscape

Manufacturing landscape of fermentation-derived product producers

The producer assessment (B2B and B2C) was created by consolidating and analyzing numerous databases, as outlined in Figure 40. The publicly available databases underlying this analysis were from GFI, Bright Green Partners, Protein Report, and the Plant Based Foods Association. Any companies identified either through additional research, responses to our survey, or interviews were also added to the long-list of alternative protein companies. Filters were applied to the list to determine how many of the companies were relevant for this study.

- Of this list of alternative protein companies, 298 highlighted fermentation as a focus, either classified as a fermentation company or mentioned fermentation in their company description.
- These companies were then reviewed one by one to remove those that are no longer active, focus on traditional fermentation (which is out of scope for this report), or focus on plant or cultured protein, only using fermentation to complement the core business. This reduced the total to 153 companies.
- Of these, we also removed any company that was not a B2B or a B2C producer, which excluded CMOs, service providers, and equipment manufacturers. This left 102 producers with a B2C, B2B, or hybrid business model.

Further research using websites, articles, publications, interviews, and survey data was conducted on each of the 102 producers to classify their customer focus (B2C or B2B), scale (lab, demo, or commercial), manufacturing method (in-house or outsourced), and location. We used these factors to produce our analysis of fermentation-derived protein producers.

2,285 companies

Consolidation of alternative protein databases
- Use publicly available databases
- Consolidate all within one database
- Remove duplicate companies
- Additional companies from desk research, interviews, and surveys

298 companies

Fermentation-focused companies
- Review for companies that state “fermentation” focus
- Remove companies with focus in other alternative proteins

153 companies

Detailed review for relevant companies
- Assess each company 1-by-1
- Remove companies that are no longer relevant:
  - No longer exist
  - Traditional fermentation focus
  - Plant, cultivated meat centric with fermentation complement

102 companies

Filtering of CMOs, providers, manufacturers
- Use publicly available databases
- Consolidate all within one database
- Remove duplicate companies
- Additional companies from desk research, interviews, and surveys

Figure 40. Producer database analysis

Global capacity for the manufacture of fermentation-derived products

As shown in Section 1, two calculations were made to size fermentation-derived product capacity:

- **Fermentation capacity –** of both CMOs and producers (B2C and B2B).
- **Annual output –** product manufactured in a given year considering available fermentation capacity.

Total fermentation capacity was calculated using the number of facilities and their individual fermentation capacity. The fermentation capacity of a facility was calculated using their specific capacity (where data was accessible) or average capacity considering a facility's scale (lab, demo, or commercial). As seen in Figures 10 and 11 in Section 1, average fermentation capacity was calculated for producers (B2C and B2B) and CMOs based on a sample of 20 for producers and a sample of 94 for CMOs. The number of facilities was taken from two different databases:

- **CMOs:** The Capacitor and the Pilots4U databases, providing the number of CMOs, their scale, location, and area of expertise.
- **Producers:** Consolidated database from GFI, Bright Green Partners, Protein Report, and the Plant Based Food Association (as described above).

This input allowed us to calculate the total fermentation capacity. As illustrated in Figure 41, a portion of the companies captured by the long-list database outsource their production to CMOs and were therefore excluded to avoid duplication.

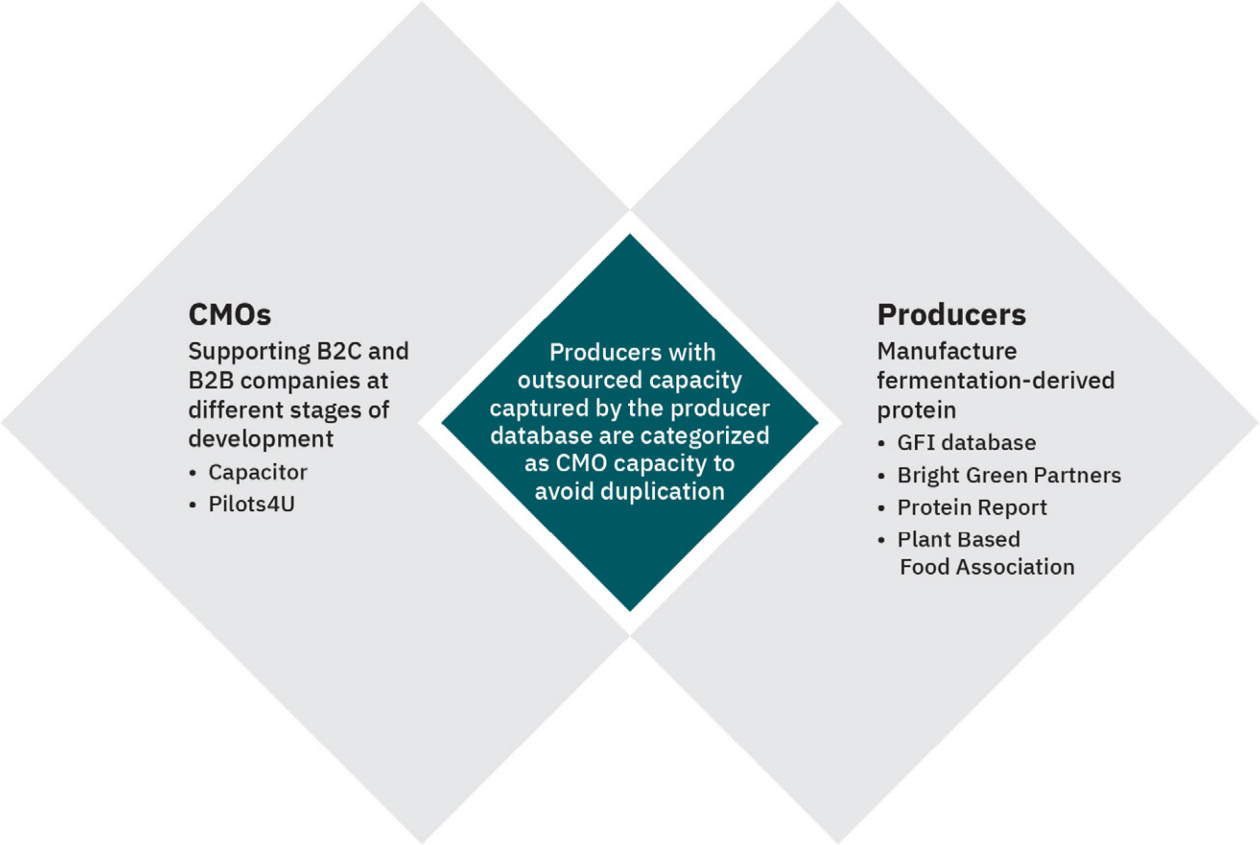


Figure 41. Fermentation manufacturer list categorization

Annual output was calculated using the method described in Section 1. The split of precision and biomass capacity was calculated using the ratio of biomass and precision-focused commercial producers: 40 percent biomass and 60 percent precision. We applied this ratio to all producers, as 90 percent of producer capacity is concentrated in commercial-scale facilities.

The overall figures presented in Section 1 consider CMOs and producers with in-house manufacturing. Producers that outsource manufacturing were not considered.

Section 2: Strategies for scaling fermentation-derived product manufacturing capacity

Data collection

Primary research: Taking an exploratory approach, 30 industry experts were interviewed covering 9 biomass and precision fermentation-focused start-ups, 10 contract manufacturing organizations, 3 experts from parallel industries, two engineering, procurement, and construction companies, 6 venture capital firms and investors, and 2 other industry-related experts. While the interviewees were predominantly based in the United States and Europe, experts from the Middle East, APAC, and Africa were also interviewed to ensure a global sample. All interviewees were anonymized in this report.

Secondary research: This report also incorporates secondary research derived from survey data, specifically to complement qualitative and quantitative findings related to the cost and time requirements for building fermentation capacity. The online survey identified the geographic location, type of operation, type of fermentation, and capacity in liters or kilograms connected to the quantitative answers provided. The survey questions covered the cost of building fermentation manufacturing capacity (cost of land and building, upstream compared to downstream processing) and the time involved as well as qualitative questions to understand recurring themes among bottlenecks and challenges identified. To access the right target group, the survey was distributed through various channels including cold emailing to fermentation companies as well as a call to action through an industry-related newsletter. Online reports, journal articles, and news articles were also consulted for background data and statistics.

Assessment

The assessments in Section 2 were carried out utilizing the qualitative and quantitative data collected as described above and via desk research.

Sections 2.1 and 2.2 assess 1) the decision between partnering with a CMO vs. building a proprietary production facility and 2) whether to build a greenfield or brownfield facility as well as buying new equipment or retrofitting equipment when building your own facility at lab, demo, and commercial production scale. Six criteria have been assessed, namely cost, skills and expertise, time, financing, process ownership, and value chain connectivity. While the clear choice between the different options depends on the individual case, the assessment provides an outline of general considerations indicating the favorable option by production scale.

Section 2.3 presents an assessment of parallel industries and the industry-related potential to leverage existing infrastructure to increase global fermentation manufacturing capacity. To arrive at a recommendation about the most favorable industries to retrofit, the section assesses process-related opportunities and availability. The assessment of process-related opportunities is based on:

- Site factors (availability of utilities, proximity to feedstock, and proximity to market).
- Functionality of upstream equipment (application of aerobic processing, cooling systems, temperature control, an impeller, bubble bioreactor technology, pressurized vessels, and production volume).
- DSP equipment utilized (centrifuges, filtration systems, and spray dryers).
- Sterilizability of machinery (production under food GMP, use of stainless steel, application of heat sterilization, chemical sterilization, radiation sterilization, and filtration sterilization).

The assessment of availability-related opportunities is based on the market factors of profit margins and year-on-year growth.

Consolidating the findings on each industry, the recommendation of the three industries (breweries, ethanol facilities, and wineries) is strongly influenced by the available opportunities and site factors since the opportunities within retrofitting remain to be further explored and validated.

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