

An Initial Pricing Analysis for a Semi-Autonomous Modular Specialty Mushroom Cultivation Chamber

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AN INITIAL PRICING ANALYSIS FOR A SEMI-AUTONOMOUS MODULAR
SPECIALTY MUSHROOM CULTIVATION CHAMBER

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Abstract

Driven by changing culinary tastes, demand for specialty edible mushroom varieties (i.e. varieties other than the button mushroom, *Agaricus bisporus*) in the United States is growing rapidly. Mushrooms have been named one of the top trends for the fourth consecutive year by food industry trend spotters. Nevertheless, domestic production lags far behind demand, leading to half of annual sales being imported from outside of the country. To help domestic growers be more competitive, a novel cultivation technology named MycoLogic has been developed to remove the variability from growing conditions, boosting annual yields and reducing costs.

As a prototype for scalable implementation, this study presents a framework and currently available information relevant to pricing decisions for a modified 40-foot sized shipping container equipped with MycoLogic's cultivation technology. Initial pricing valuations estimate that each MycoLogic module can create between \$46,602 and \$161,809 of added value over its 20-year lifetime. A sensitivity analysis demonstrates that the two most sensitive variables affecting this value are the average price per pound of mushrooms and the yield per five-pound block of substrate. At this early phase, it costs an estimated \$15,962 to manufacture each cultivation module. In the future, a standardized method to compare mushroom yields across cultivation techniques and structures will be developed to quantify differences in yields, provide benchmarks, and estimate yields from new projects.

BIOGRAPHICAL SKETCH

Luc Lalire grew up outside New York City in Palisades, New York. He developed a love for the natural world during hiking and camping trips in the Catskills and became skilled at foraging for wild edible mushrooms during summers in Maine. He studied Biology at the University of Vermont, eventually receiving his Bachelor of Science in Integrative Biological Studies with minors in Chemistry and History. After graduation, he moved to Denver where he spent a year working in a research lab studying Idiopathic Pulmonary Fibrosis at National Jewish Health, before transitioning into Research and Development at the medical device company, Corgenix. It was while sharing his Denver apartment with a chef that Luc discovered another passion, his love of cooking and good food.

After bringing multiple successful projects to completion at Corgenix, Luc made the transition from R&D to sales by joining the chemistry sales team at Waters Corporation in Boston. During his time at Waters, Luc developed a wide range of management skills, meeting tight deadlines and sales quotas while cultivating relationships with a wide variety of pharmaceutical, biopharmaceutical and specialty chemical companies. This experience honed his ability to generate revenues efficiently in a highly technical industry. During the pandemic lockdown, Luc began to read about ecological problems affecting agriculture and the food chain, and thought deeply about his personal responsibilities in a rapidly changing climate. He started exploring new developments in Controlled Environment Agriculture. Because the nascent industry perfectly combines his deeply felt passions for the biological sciences, for benefiting society with environmentally sound technology, and not least, a love of edible mushrooms and fine cooking, Luc decided to leave Waters Corp. to pursue a Master of Professional Studies with the Cornell CEA program.

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I would like, first and foremost, to thank my advisor Prof. Neil Mattson for his support, which began before I was admitted into the program and has continued consistently up to the final stages of this project. He was accepting and encouraging in my specific approach to my degree program, allowing me to achieve everything I hoped for from my studies at Cornell. I look forward to staying in touch as we continue down our respective paths in the CEA industry.

Next, I would like to thank Dr. Chris Cornelison, Dr. Kyle Gabriel, and Will Beeson at Kennesaw State University in Georgia for inviting me to join their fascinating work on specialty mushroom cultivation. Both the timing and focus of the opportunity could not have been better. I am excited to watch MycoLogic evolve from an early pilot study into an effective technology in active use by mushroom cultivators across the country.

I also would like to thank Prof. Harry Kaiser and the many other Dyson School professors who took time out of their days to advise me on this work. Their input directed my focus and saved me many hours of research in the planning of this paper.

Finally, I would like to thank my family for their unending confidence in my endeavors. Their caring, wisdom, and ability to know when to provide help and when to stand back has always been appreciated. I certainly wouldn't have made it to Cornell or anywhere else without them.

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Introduction

Specialty mushrooms (an industry term used for any mushroom not considered a button mushroom [in the *Agaricus genus*]), is the fastest growing segment of mushroom sales in the United States. Retail sales for specialty mushrooms increased an average of 46% between 2016 and 2021, while *Agaricus* mushroom sales only increased by 1% (Mushroom Retail Tracker Report by Mushroom Council). In 2021, 39.3 million pounds of specialty mushrooms were sold in the U.S., generating between \$123 million and \$170 million at the point of first sale. For reference, the USDA reports button mushroom sales in the U.S. reached \$998 million in 2021. Approximately half of this quantity was imported, and the rest grown in the United States by approximately 500 domestic growers. Despite this growth, domestic production remains relatively small scale and unsophisticated. A major reason for this is the lack of institutional support and lack of investment in technology that could improve specialty mushroom cultivation techniques. Improving the quantity and quality of cultivation knowledge is essential for increasing the number and quantity of U.S. based growers, and this has the potential to drive additional growth to this industry.

While mushrooms are sold in grocery stores in the vegetable section, edible fungi (otherwise known as mushrooms) occupy an entirely distinct kingdom from plants. As heterotrophs, fungi cannot manufacture required nutrients but instead, depend on sourcing carbon from the surrounding environment for their nutrition (Asiegbu et al., 2021). In order to access these nutrients, fungi produce a diverse range of extracellular enzymes to decompose the complex substrates that surround them (Asiegbu et al., 2021). This role of decomposer plays a critical role in the environment and has the potential to play an equally significant role in agriculture, because the primary food source of mushrooms are lignocellulose materials. Lignocellulose materials

happen to be one of the most abundant and renewable resources on earth and a direct waste stream from many forms of agriculture (Zoghalmi et al., 2019).

There are at least two thousand species of edible mushrooms on Earth (Huili et al., 2021). However, for variety of reasons, many cannot be cultivated and are exclusively acquired via foraging. The mushrooms that can be cultivated are further separated into two categories: button mushrooms (*Agaricus bisporus*) and specialty mushrooms. Button mushrooms are the most common cultivated variety and although they are sold under names such as brown, white, button and portabella, they are in reality only one species of mushroom. Specialty mushrooms incorporate all other commercially cultivated species of mushrooms; the two most common varieties are Oyster (*Pleurotus ostreatus*) and Shiitake (*Lentinula edodes*), but there are many others, including Lion's Mane (*Hericium erinaceus*), Maitake (*Grifola frondose*), and Enoki (*Flammulina velutipes*) (Defining the Specialty Mushroom industry, Cornell Small Farms Program). Due to a combination of economics and specific cultivation traits, specialty mushrooms are grown using a different set of techniques and equipment than button mushrooms.

Indoor specialty mushroom cultivation involves several distinct steps that can, and often are, decoupled from one another. Cultivation begins with a culture of a selected strain of mushroom that has been harvested from spore or a tissue sample (Stamets, 1996). This culture is maintained on an agar plate in a sterile environment and then inoculated into a quantity of sterilized substrate, most commonly grain or a combination of sawdust and bran. Mycelium (the filamentous roots of the fungi) are allowed to propagate throughout the substrate until it is fully saturated. This step is referred to as spawn. It can be incubated or used immediately to inoculate bulk substrate. The composition of the bulk substrate varies by variety but will include a mix of lignocellulosic material (sawdust, straw, paper chips, corn fiber, rice hulls, etc.) and often

supplemented with additional nutrients such as proteins, starches, yeast, and minerals. Depending on the size and preference of the mushroom operation, bulk substrate is spread out over trays or packed into plastic bottles or 5- and 10-pound bags. As the mycelium is not in direct contact with the outside environment up to this point, outside conditions have a relatively minor effect on the process. This period is referred to as the colonization period and can last anywhere from 2-6 weeks. The final stage of cultivation is the fruiting stage in which the fruiting body of the mushroom (the edible part of the mushroom and only portion that extends above the surface of the substrate) is induced to form. Here, environmental conditions are supremely important because mushrooms form best when temperature, humidity, CO₂ levels and light are held constant within a range specific to that variety of mushroom (Stamets, 1996). Once fully formed, mushrooms are then harvested, packaged and sold.

Surprisingly, the techniques for growing specialty mushrooms described above have remained relatively consistent for the past 50 years, as the use of sawdust blocks for the purpose of commercial mushroom cultivation was first reported in the 1970s (Defining the Specialty Mushroom industry). Since then, the specialty mushroom industry has grown steadily and consistently faster than the overall mushroom industry. However, the lack of research and lack of investment by large commercial operations in advanced and improved growing technologies means that domestic producers cannot grow specialty mushrooms fast enough to meet the rapid growth in demand due to a lack of production knowledge and industry organization. In order to help address this gap, the novel cultivation technology MycoLogic has been developed to employ new technologies to optimize environmental conditions during the crucial fruiting stage of mushroom cultivation, with the goal of dramatically increasing the yield and frequency of harvests.

MycoLogic, is a semi-autonomous drop-in environmental controller that enables the scalable optimization of specialty mushroom fruiting using embedded systems and a proprietary software. The system can be installed in standardized shipping containers or existing structures and facilities. When it optimizes environmental parameters, it allows growers to maximize output by matching fruiting conditions to their chosen mushroom crop. The end result is an increase in profitability of existing farms and a lowered barrier for new entrants. In order to move this technology toward the open market, this report proposes a rigorous analytical framework that provides initial cost estimates to assemble and a range of value estimates for a fully modified 40ft production module equipped with MycoLogic's production technology.

Market Analysis

In order to better understand the market for specialty mushrooms in the United States, a market analysis was performed. Figures for annual consumption of specialty mushrooms in this country are not readily available, so this analysis was estimated based on a combination of USDA production reports (Mushrooms, USDA Survey) combined with USDA Census data (U.S. Trade Online) tracking imports. Domestic production is roughly equivalent to the quantity imported into the country each year. Exports are negligible, being less than 10% (roughly 1.5 to 3 million pounds), and this number is decreasing. In 2021, the size of the U.S. specialty market at the point of first sale was between \$126 million and \$177 million. However, due to the methods the USDA utilizes for data collection, the true quantity of domestically produced specialty mushrooms could be significantly higher. An unknown portion of specialty mushroom cultivation is performed via cottage industry. These operations often utilize homemade facilities, sell their produce locally, and don't report the sales.

The USDA National Agricultural Statistics Service (NASS) includes Specialty Mushrooms as part of their annual voluntary survey of agricultural producers. In 2010, it reported a total domestic production of 16.4 million pounds of specialty mushrooms. A decade later, in 2021, that figure rose to 21.5 million pounds, a 24% increase. Of that total, 7.4 million were Shiitake, 7.2 million were Oyster and the remaining 6.8 million accounted for all other varieties of specialty mushrooms (Mushrooms, 2021). In terms of sales, the USDA reports \$66.1 million dollars of sales in 2021. This is a 40% increase from the value reported in 2010. It should be noted that the USDA collects data via a voluntary survey and responses to this survey have been on the decline for the past decade (Johansson et al., 2017). So, it is likely that domestic production figures are higher than what has been reported to the USDA.

In addition to domestic production, the United States also imports a significant quantity of specialty mushrooms, and this is tracked by the Foreign Trade Division of the U.S. Census Bureau (U.S. Trade Online, 2022). Detail on domestic production and imports can be found in figure 1.

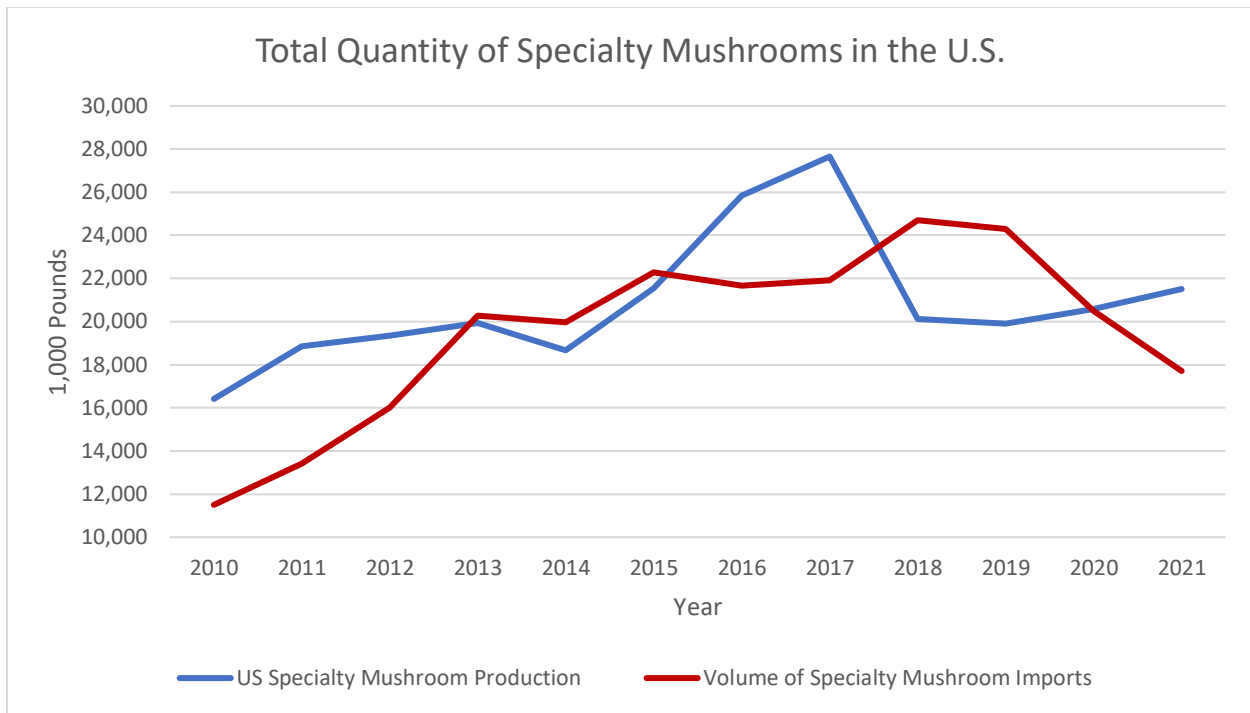


Figure 1. Total quantity of specialty mushrooms in the U.S. between 2010 and 2021.

Based on the combined volumes of imports and domestic production shown in figure 1., there were approximately 39.3 million pounds of specialty mushrooms available for consumption in the U.S. in 2021 (USDA-NASS, U.S. Census Bureau). By subtracting the volume of specialty mushroom exports (as shown in Figure 2), it is estimated that 37.6 million pounds of specialty mushrooms were consumed in the U.S. in 2021. When expressed as a percentage, imports represented nearly 92% the size of domestic production when averaged over the past 10 years. Exports made up an average of 11% of domestic production over the past 10 years. The trends established over the past decade indicate that demand for specialty mushrooms in the U.S. has an approximate annual growth rate of 3% and a CAGR of 4.3%.

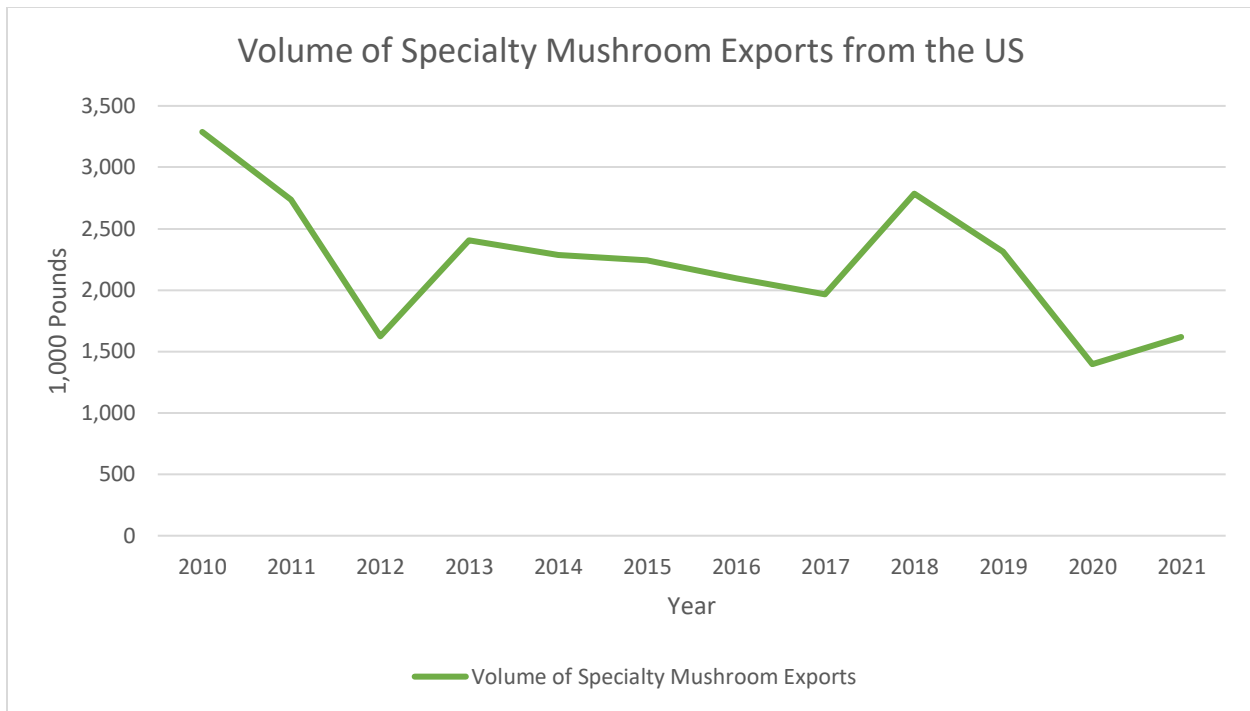


Figure 2. Total quantity of specialty mushrooms exported from the U.S. between 2010 and 2021. Export data courtesy of the Foreign Trade Division of the U.S. Census Bureau.

The USDA-NASS survey estimates that the total value of specialty mushroom sales in 2021 in the U.S. was \$66.1 million (Mushrooms, 2021). This estimate does not include the value of mushroom imports in its calculations. If the price per pound (\$3.21/lb) reported by the USDA is extended to both domestic production and to imports, the estimated total value of the wholesale specialty mushroom market was \$126 million in 2021. However, the average price per pound reported by the U.S. Census Bureau is much higher, at an average of \$6.12 per pound which indicates that the estimate of \$126 million should be considered the minimum possible value for total sales of specialty mushrooms in 2021. When each sales price (imports vs. domestically grown) is applied to its respective category of mushrooms, the estimated aggregate sales of specialty mushrooms in 2021 is \$177.5 million dollars at the point of first sale.

Additional insight comes from data collected by retailers. Major retail outlets across the country regularly report trends in produce sales, and industry advocacy organizations collect and

report these figures to track trends nationwide. While these retail sales only represent a fraction of total specialty sales, they can be used to approximate the make-up and geographic distribution of demand for specialty mushrooms. In agreement with the USDA figures, retail data shows that Shiitake mushrooms are the most popular, occupying 72% of specialty mushrooms sales (Mushroom Retail Tracker Report by Mushroom Council). Oyster mushrooms are the 2nd best seller in retail locations, accounting for 9% of sales. Detail on the distribution of the remaining 19% of sales can be found in tables 6 and 7. In terms of geographic distribution, the Northeast is responsible for 30% of retail sales followed by the Mid-South (16%) and the Great Lakes region (14%). California, the West, and the Southeast represent approximately 12-13% of sales each and the South-Central region represent the smallest percentage of sales at 3% (Mushroom Retail Tracker Report by Mushroom Council) (See Figure 3). Based on a 2003 analysis, mushroom consumption is highest in suburban areas (4.3 lbs per capita), followed by metropolitan areas (3.3 lbs. per capita) (Lucier et al., 2003). It is also positively correlated with income and is highest among Asian (6.1 lbs. per capita) and non-Hispanic white (3.0 lbs. per capita) populations (Lucier et al., 2003).



Figure 3. IRI Standard Regions. Image courtesy of the Mushroom Council

Specialty mushroom producers can be divided into two categories: full time cultivators who exclusively produce mushrooms, and part-time growers who supplement their revenue with

specialty mushroom cultivation. According to a 2021 survey of 135 specialty mushroom growers conducted by the Cornell Small Farms Program, one third of specialty mushroom cultivators are full-timers, while the remaining two thirds produce other crops in addition to mushrooms (Gabriel et al., 2020). In terms of revenue, 73% of respondents reported annual sales of \$50,000 or less. The average age of respondent's businesses is 6.9 years even though 59% of respondents indicate they have been in business for 5 years or less. (Cornell Mushroom Survey, 2020). This disparity could be explained because low barriers to entry encourage entry despite lack of production experience or skills. In effect, many small-scale producers are operating as an informal cottage industry. Information on production techniques is not well distributed which leads to disparities in farm profitability (Gold, Michael A et al., 2008). In support of this statement, only 26% of indoor cultivators report the use of a dedicated building designed for mushroom production (Gabriel et al., 2020).

In addition to a wholesale model primarily targeting distributors and grocery stores, many specialty mushroom cultivators pursue direct to customer sales to complement or as an alternative to distributors. Direct to consumer approaches utilize farmers markets, farm stands, restaurant sales, CSAs and direct to individual sales through the internet. The most common direct to consumer channels are farmers markets (38%), restaurants (16%) and then farm stands (12%) (Gabriel et al., 2020). This approach can require additional labor in the form of marketing and distribution but yields a significantly higher price per pound than wholesale rates. Direct to consumer prices average \$15.99/lb with reported prices reaching as high as \$25/lb (Gabriel et al., 2020). Incentivized by these high prices, direct-to-consumer sales are very common among small to mid-size cultivators. Respondents to the Cornell Farms Survey reported 71% of their sales were through one or more of these direct channels (farmer's markets, restaurants, roadside

stands, CSAs, and individual sales). It is unclear what portion, if any, of these sales are recorded by national retail tracking of mushroom sales. As a result, the true size of the specialty mushroom market in the U.S. has the potential to be quite a bit larger than national tracking reports suggest.

The USDA no longer tracks the number of specialty mushroom growers as part of their annual mushroom survey but in the last year it was reported separately (2017), 226 commercial growers responded to the survey (USDA-NASS, 2018). Industry agricultural extensions specialists estimate the total number of specialty mushroom cultivators in 2021 to be somewhere between 450-500 nationally, 300 of who are categorized as small to mid-size in scale. Surveys of cultivators have consistently found that they expect demand for their specialty mushrooms to increase in the coming years. A 2014 survey of Northeastern cultivators found that 71% expected demand for Shiitake mushrooms to increase over the next five years (Matthews, 2015). Seven years later, a separate survey of East Coast cultivators conducted in 2021 indicated that 64% were experiencing a demand higher than they could supply and 80% were planning on expanding annual production (Gabriel et al., 2020).

At the moment, there are two shipping container-based cultivation systems on the market. One, manufactured by Cropbox appears to not be available now as very little detail is available and no option to place an order. The second, the Gourmet Mushroom Farm (GMF) offered by FarmBox Foods includes equipment for substrate preparation, a laminar flow cabinet for inoculations, incubation space and a fruiting chamber. Brand new, a GMF costs \$150,000. Finally, there are two Dutch companies that provide custom solution to large scale mushroom cultivators. Fancom and Christiaens Group both build large custom mushroom cultivation facilities that include sophisticated climate control in both incubation and fruiting areas.

There are powerful, new indicators from both consumers and investors that demand for specialty mushrooms will continue its strong growth. Mushrooms have been named one of the top trends for the fourth consecutive year by food industry trend spotters (*Mushrooms Continue to Trend as 'Ingredient of the Year'*, 2022). In 2022, the New York Times named mushrooms the “ingredient of the year” (Severson, 2021) Additionally, Smallhold, a specialty mushroom start-up based in Brooklyn NY, recently announced a \$25 million Series A funding round marking the first successful fundraising round by a dedicated specialty mushroom cultivator (Sorvino, 2021). This demonstrates that established investors are beginning to take notice of the specialty mushroom industry.

SWOT analysis

To understand MycoLogic’s potential position in this emerging market, an analysis was performed of its strengths, weakness, opportunities, and threats, using the module in its current form (See Table 1). Many of the current strengths of the module are inherent to its design. The modular and independent nature of the structure allows for considerable flexibility in location and ease of use in operation. This is an advantage compared to traditional methods, where commercial fruiting rooms are typically repurposed structures or DIY projects built by the farmers themselves. While home-made options are cheaper alternative to MycoLogic, the results are highly inconsistent due to the wide range of available resources and experience, which can lead to disappointing yields. Yield is largely dependent on the ability to maintain consistent species-specific environment conditions. As demonstrated later in this paper, the mushroom yield per quantity of substrate is one of the most important figures in achieving profitability in specialty mushroom cultivation.

The current weaknesses of the MycoLogic production module can be split into two general categories; those inherent in the design, and those related to its implementation. For example, the current design uses shipping containers that have inconsistent availability and naturally have a ceiling to attainable levels of economies of scale fall in terms of cultivation space and automation. Implementation weaknesses will need to be improved for all current and future products. These include the user interface, control software, and substrate concerns.

Table 1. A SWOT analysis of the MycoLogic production module in its current form.

SWOT Analysis: MycoLogic Production Module	
Positive:	Negative
<p>Strengths:</p> <ul style="list-style-type: none"> - Turnkey, comes ready to use - Can be independently deployed - Capable of supporting a wide variety of specialty mushrooms - Capable of remote operation - Source of stable employment - Resistant to extreme weather events - Minimal upfront costs for fabrication and delivery - Designed using feedback from multiple professional cultivators - Clean-in place sanitation ensures effective and quick cleaning protocol - Can be located at or near areas of high demand - Harvests can be scheduled via climate controls - Low power and water requirements 	<p>Weaknesses:</p> <ul style="list-style-type: none"> - Software is dependent on continuous support to remain competitive - Dependent on availability of shipping containers - Modular nature creates ceiling for economies of scale - Does not address substrate related issues - Large upfront cost will be prohibitive to many cultivators - No UI for customer control - No partitioning inside of module, thus can only maintain one set of environmental setpoints

<p>Opportunities:</p> <ul style="list-style-type: none"> - Capable of tapping into functional mushroom cultivation (nutraceutical and pharmaceutical) - Manufacturing can be streamlined via 3rd party manufacturers - Core technology is compatible with a wide range of structures - Potential for additional features to be incorporated into environmental control unit - Spent substrate is a valuable compost ingredient 	<p>Threats:</p> <ul style="list-style-type: none"> - Average price per pound could fall as total production increases - Cultivators are distributed over a large geographic territory - At least two competitors already available on the market - Market consolidation - Large established mushroom growers develop internal systems
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Both the opportunities and threats currently facing MycoLogic are long term considerations rather than immediate concerns. The environmental controller is a standalone module which provides opportunities in both its deployment and assembly. Beyond its application for use with shipping containers, the controller is compatible with a variety of structures as long as they meet a set of requirements regarding insulation, ventilation and cleanliness. Manufacturing costs can be reduced by partnering with specialized manufacturing firms that can produce bulk orders of individual components. Data logging, a post-harvest storage mode and other features to improve the experience of the grower and quality of mushrooms produced can be added to increase the value of the product. Finally, culinary uses are only one application for specialty mushroom cultivation. The use of mushrooms for pharmaceutical and nutraceutical purposes, a practice that has occurred since ancient times, is increasingly being validated by scientific study and represents a second potential market for specialty mushroom cultivation (Niego et al., 2021)).

A significant risk in the long run of increasing the scale and sophistication of specialty mushroom cultivation is that this will be likely to cause a drop in the price per pound. This will

put pressure on growers and may drive consolidation as less competitive growers are acquired or exit the market. This would reduce the potential number of customers for MycoLogic. This threat might be magnified by the presence of large established button mushroom growers that may flood the market with specialty mushrooms if they deem the market profitable enough to do so. Additionally, the existing cultivation modules available in the U.S. which could lead to faster saturation of the market and force coverage to be stretched over a larger geographic area.

Cost Outline

To understand the costs associated with assembling production modules, a cost outline was prepared to determine the estimated cost per unit in the first year of operation. This outline was prepared using all information available at the time of writing (interviews with designers, growers, and, mushroom cultivation guides). As additional information is learned and experience gained, this estimate can be refined to yield a more precise costing.

The costing summary in Table 2 is the estimated cost per unit for MycoLogic's first year of operation. The costing model assumes 15 modules being constructed in the first year of operation. The operation would be in Gilmer County, Georgia, and functioning in a partnership with an existing mushroom cultivation operation. The hourly manufacturing rate is estimated to be \$22.90/hour. This is based on the national median wage rate for Farm Equipment Mechanics and Service Technicians in the Equipment merchant category (Farm Equipment Mechanics and Service Technicians, 2021). Material costs were determined based on the cost of the modules constructed to date. As the scale increases, it is assumed material costs per unit will decrease.

To estimate the number of direct and indirect person hours related to manufacturing and selling each module, interviews were conducted with members of the manufacturing and support team and the results aggregated into an average estimate for each task. At this point, module

construction will require an average of 37.5 person hours of direct assembly plus 2.5 hours for an independent contractor as needed. When additional hiring and employment fees are considered, this equals \$18,778 in direct labor in the first year of operation. Based on customer interactions to date, there is estimated to be 470 hours (or \$13,451) of indirect labor associated with the first year of operation. Module shipping and individual customer support are not included in these estimates as these services will be charged separately.

Table 2. Cost of goods estimate for MycoLogic's first year of operation where 15 modules are constructed and sold.

COGS Expenses	Amount
Direct materials	\$197,979
Direct Labor	\$18,778
Server Upkeep	\$460
Indirect Labor	\$13,454
Supplies	\$6,750
Utilities	\$2,023
Est. Annual Cost	\$239,444
Est. Cost Per Unit	\$15,963

Value Estimate

To create a value estimation, a single hypothetical 40 ft. module was analyzed. A critical component to determining the appropriate price for each module is establishing the total value created over its functional lifetime. This value provides a quantitative figure which can be compared against alternative solutions can also be compared with completely unrelated projects. To do this, a net present value calculation was used to estimate the acceptable size of initial investment based on all future cash flows. The equation used can be found in Figure 3.

$$\text{Maximum acceptable initial investment} = \sum_{i=t}^n \frac{R_i}{(1+r)^i}$$

Figure 4. Equation used to calculate net value of production modules where R_i equals the annual net revenue, r equals the discount rate, and t represents the number of years the module is in operation.

For the purposes of this model, the following parameters were set: one 40 ft. module is used to grow *Pleurotus ostreatus*, the Blue Oyster variety, for the duration of the cultivation container's functional lifetime (20 years). The theoretical farms are in Gilmer County, Georgia, to ensure equivalent and reasonable sales and input prices. The hypothetical module is used to expand an existing mushroom operation and is not replacing any previous structure. The modules are in operation 365 days a year, except for three days per harvest cycle (which lasts for 33-48 days) for cleaning and repairs. Each cycle requires 400 blocks of 5 lb substrate (wet) that is either purchased pre-inoculated or prepared onsite. It is assumed that 100% of these bags are harvested and sold (i.e., no losses due to contamination) and that employees cost 1.25x their hourly rates to account for fringe benefits (employer portion of social security, Medicare, and unemployment insurance and contribution to employee health insurance). Spent substrate can then be sold as mulch at a rate of \$53 per cubic yard to landscapers, farmers, and gardeners. Labor rates are based on national hourly mean wage rates for crop production in greenhouses which is \$14.98 per hour (Farmworkers and Laborers, Crop, Nursery, and Greenhouse, 2021). The discount rate used is the average return on assets for the U.S. farm sector since 1973 (7.3%) (Langemeier, 2020). A full list of assumptions used for this analysis can be found in Table 8.

Once these parameters were established, three sets of inputs were created that represent possible scenarios a mushroom grower might experience while using a production module (See Table 3). Scenario 1 represents a small-scale cultivator who sells directly to consumers, uses pre-inoculated blocks, and has a relatively low average yield per block (518g/block). This cultivator

is, however, able to sell to consumers directly at a high average price per pound of \$20.16/lb.

The second scenario is the same as the first except their average yield per block has increased to 873g per block. As a result of the increased production, the average price per pound they are receiving has fallen to \$15.00/lb. The third scenario represents a wholesale model. In this situation, the price per pound (\$5.33/lb) is much lower but the grower can compensate for that by reduced distribution costs and lower cultivation costs due to self-manufactured substrate. Both the yields and prices utilized in the above scenarios are actual values reported by specialty mushroom growers in the Greater Atlanta area.

To estimate costs, quotes for pre-inoculated substrate and master spawn were retrieved from two mushroom supply companies. Field and Forrest offered the best quote, of those contacted, for pre-inoculated substrate at \$6 per 5 lb block plus shipping and North Spore offered a quote of \$11.10 per bag of spawn. Distribution costs are based on costs reported by the Cornell Small Farms Sample Budget for Shiitake Cultivators (Business Planning, Cornell Small Farms).

Table 3. Inputs into the financial model for each of the three possible scenarios.

	Scenario 1	Scenario 2	Scenario 3
Customer Type	Direct to Consumer	Direct to Consumer	Wholesale
Average yield per block	518g	873g	873g
Blocks per year	3,476	3,244	3,244
Average price per pound	\$20.16	\$15.00	\$5.33
Pre-inoculated substrate price	\$6.00	\$6.00	NA
Mushroom Spawn	NA	NA	\$11.20
Fresh Substrate	NA	NA	\$1/5lb bag
Hours of labor per week	12	12	16

Each set of inputs was entered into the financial model, while all other variables were held constant. The model assumes one lost cultivation cycle in the first year of operation, and assumes that spent substrate sales are not established until the second year of production.

Years 2-20 assume constant production throughout the year. As can be seen in Table 4, scenario 2 yields the largest annual net benefits of \$16,003 per container. The wholesale model in scenario 3 yields the smallest annual benefits of \$4,720. A significant addition to the cultivation cost in scenarios 1 and 2 is the price of shipping the pre-inoculated substrate to the farm. For scenario 1 of the \$55,003 in cultivation costs, 33% is generated by shipping of the substrate to the farm. While homemade substrate blocks have the potential to be the most cost-effective approach to cultivation, special attention should be paid to quality, ensuring the yield per block of homemade substrate matches that of the pre-inoculated blocks.

Table 4. Projected annual revenue for each scenario.

Income	Scenario 1	Scenario 2	Scenario 3
Fresh Mushroom Sales	\$ 80,031	\$ 93,684	\$ 33,289
Secondary Sales	\$ 2,619	\$ 2,444	\$ 2,444
Total Income	\$ 82,650	\$ 96,128	\$ 35,733
Variable Costs			
Cultivation Costs	\$55,003	\$52,475	\$23,910
Distribution Costs	\$14,871	\$23,396	\$ 5,849
Net Income Before Taxes	\$ 12,776	\$ 20,257	\$ 5,974
Tax Provision	21%	21%	21%
Net Income	\$ 10,093	\$ 16,003	\$ 4,720
Annual Net Benefit	\$ 10,093	\$ 16,003	\$ 4,720

Once the net benefits were calculated for years 1 through 20, each year was discounted back to year 0 using the previously mentioned discount rate. The sum of these values over the 20-year lifetime of the module represents the estimated total value of the module. Based on the three scenarios, the total value of a 40 ft. production module is between \$46,602 and \$161,810. The average net present value across the three scenarios is \$103,127.

Table 5. Present value of the module for each scenario.

	Scenario 1	Scenario 2	Scenario 3
Annual Mushroom Production (lbs)	3970	6246	6246
Annual Revenue	\$10,093	\$16,003	\$4,720
Present Value of Module	\$100,969	\$161,810	\$46,602
	Average Net Present Value of Module	\$103,127	

Sensitivity Analysis

In order to guide the focus of future investigations into the value of a MycoLogic production module, a sensitivity analysis was performed to identify which variables had the greatest effect on the net present value of the module. The five variables with the highest potential for change were selected for inclusion. They were: the average price per pound of mushrooms, the discount rate, the yield per bag, the total cost per bag and, the hours of labor required per week. Working on each variable, one at a time, the net present value of the module was determined when the value was either increased or decreased by 10%. In order to keep the changes equivalent, the discount rate was increased and decreased by 1%.

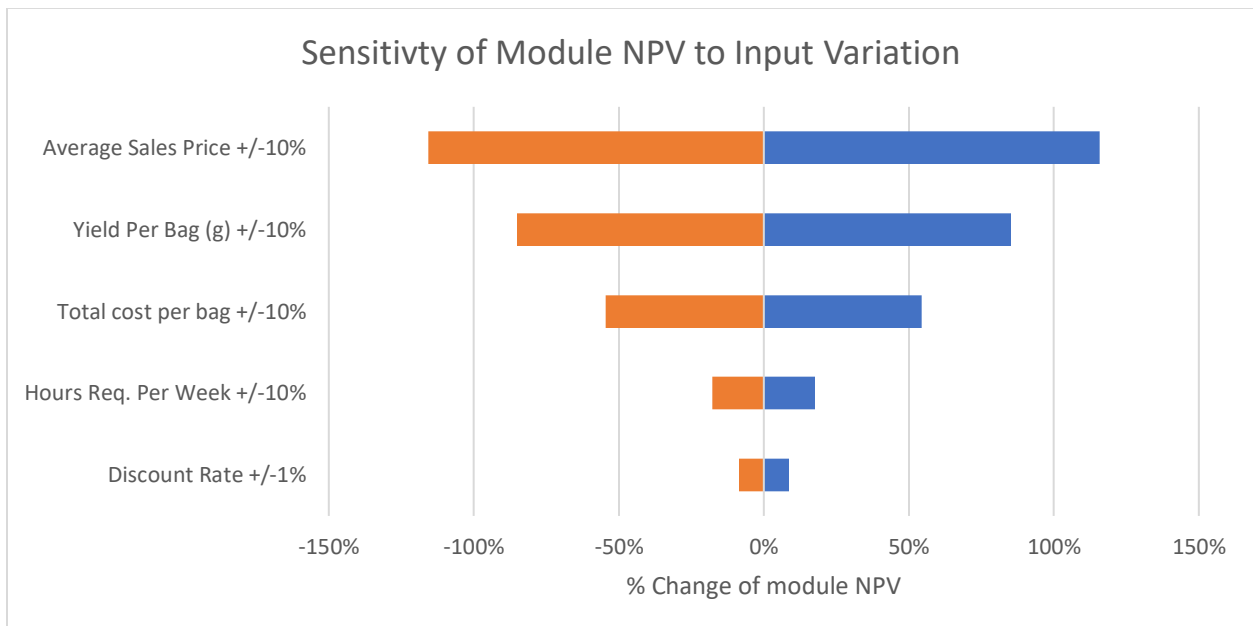


Figure 5. Results of the sensitivity analysis on module pricing

The average sales price of the mushrooms had the largest effect on the final value. A 10% change in sales price varies the total net present value of the module by 116%. The yield per bag had a smaller but still large influence on the final value. A 10% shift in the yield per bag alters the value of the module by 85%. The third most influential variable on the end value is the total cost per bag of inoculated substrate. A 10% shift in this figure alters the final number by 55%. As additional data becomes available, special attention should be paid to ensuring that the mean and variation of the sales price, the yield per bag (or per kg), and cost per bag is closely tracked across geographies and business models.

Conclusions

This analysis provides an initial framework with which to make decisions on pricing strategies for a 40ft MycoLogic production module. In its current form, the MycoLogic production module provides many innate strengths but will require additional features and support for it to be most effective. It will cost approximately \$16,000 to manufacture each module in the first year of operation. This cost could rise as the quantity of indirect labor and overhead increases. The cost could be reduced by streamlining manufacturing, reducing the material cost via negotiation and/or outsourcing certain portions of manufacturing to specialist manufacturing firms.

The three scenarios presented above suggest the total potential value of a 40ft product module lies between \$46,602 and \$161,809. The current state of the industry suggests that an upfront purchase of this size would be prohibitive for a large portion of specialty mushroom cultivators. A leasing agreement would allow a greater percentage of cultivators to access this

scale of production. Additionally, smaller sizes of production modules have the potential to still be profitable while less resource intensive for small scale growers.

The average price per pound of mushroom sales has the largest effect on profitability. Production modules can have an indirect effect on price per pound by increasing mushroom quality and being located geographically to be near demand and to reduce transportation distance. The module will have a more direct influence on the yield per bag of substrate, which is the second most important factor in profitability. Yield should be emphasized as a critical point for future investigations and interactions with growers. The information provided in this analysis is intended as an initial estimate of costs and range of potential value based on the data available at this time. Future work should determine lowest viable yields and target yield values for 40ft modules using the most commonly cultivated/relevant strains of specialty mushrooms.

The considerable variability and informal nature of the industry requires large quantities of data to ensure accurate estimates of current cultivation costs, yields and profits. As this data is gathered, standard methods for quantifying yield should be developed that take the yield per kg of substrate, number of flushes, and days until each flush into account. This standard will allow performance of different mushroom techniques to be easily compared against one another. More critically, it will allow the rapid quantification of incremental gains. Quantifying incremental gains will be critical to further pricing analyses of MycoLogic technologies.

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Appendix:

Table 6. Changes in retail sales of mushrooms in dollars between 2021 and 2018 (Mushroom Retail Tracker Report by Mushroom Council, 2022).

Dollar Value of Sales	2021-2022	2020-2021	Dollar Sales % Change vs YA	2019-2020	Dollar Sales % Change vs 2 YA	2018-2019	Dollar Sales % Change vs 3 YA
Specialty Mushrooms	\$74,318,420	\$82,169,176	-9.6%	\$64,878,767	14.5%	\$56,702,560	31.1%
All Other Mushrooms	\$12,965,155	\$17,307,424	-25.1%	\$15,549,218	-16.6%	\$14,809,792	-12.5%
Black Forest Mushrooms	\$7,573	\$7,658	-1.1%	\$6,222	21.7%	\$5,320	42.3%
Chantrelle Mushrooms	\$603,110	\$768,543	-21.5%	\$317,098	90.2%	\$306,216	97.0%
Enoki Mushrooms	\$301,881	\$367,693	-17.9%	\$588,984	-48.7%	\$471,415	-36.0%
Morel Mushrooms	\$180,015	\$126,521	42.3%	\$221,837	-18.9%	\$181,998	-1.1%
Oyster Mushrooms	\$6,868,181	\$7,205,368	-4.7%	\$5,568,340	23.3%	\$4,747,262	44.7%
Porcini Mushrooms	\$18,291	\$37,988	-51.9%	\$58,782	-68.9%	\$81,695	-77.6%
Shiitake Mushrooms	\$53,342,957	\$56,305,389	-5.3%	\$42,515,237	25.5%	\$36,036,727	48.0%
Wood Ear Mushrooms	\$31,257	\$42,591	-26.6%	\$53,048	-41.1%	\$62,135	-49.7%
White Mushrooms (Button)	\$688,239,808	\$752,290,656	-8.5%	\$698,962,313	-1.5%	\$673,279,797	2.2%
Crimini/Brown Mushrooms	\$394,600,403	\$415,039,670	-4.9%	\$347,251,916	13.6%	\$295,097,180	33.7%

Table 7. Changes in retail sales of mushrooms in pounds between 2021 and 2018. (Mushroom Retail Tracker Report by Mushroom Council, 2022).

Volume of Sales (lbs)	2021-2022	2020-2021	Dollar Sales % Change vs YA	2019-2020	Dollar Sales % Change vs 2 YA	2018-2019	Dollar Sales % Change vs 3 YA
Specialty Mushrooms	5,640,899	6,655,137	-15.2%	5,442,904	3.6%	5,082,717	11.0%
All Other Mushrooms	1,435,118	1,789,473	-19.8%	1,635,531	-12.3%	1,710,339	-16.1%
Black Forest Mushrooms	1,052	1,414	-25.6%	1,260	-16.5%	970	8.4%
Chantrelle Mushrooms	35,580	57,414	-38.0%	15,210	133.9%	14,743	141.3%
Enoki Mushrooms	24,045	54,349	-55.8%	80,754	-70.2%	45,126	-46.7%
Morel Mushrooms	4,897	3,583	36.7%	5,893	-16.9%	4,824	1.5%
Oyster Mushrooms	592,137	635,652	-6.8%	546,423	8.4%	500,977	18.2%
Porcini Mushrooms	411	851	-51.7%	1,347	-69.5%	1,793	-77.1%
Shiitake Mushrooms	3,544,800	4,108,344	-13.7%	3,151,593	12.5%	2,798,046	26.7%
Wood Ear Mushrooms	2,858	4,057	-29.5%	4,892	-41.6%	5,898	-51.5%
White Mushrooms	177,155,124	200,076,366	-11.5%	188,112,022	-5.8%	186,275,235	-4.9%
Crimini/Brown Mushrooms	87,076,112	95,144,826	-8.5%	79,518,806	9.5%	67,717,259	28.6%
Portabella Mushrooms	22,602,681	25,023,445	-9.7%	22,931,628	-1.4%	25,148,347	-10.1%

Table 8. Full list of assumptions used for estimating cost and value of 40ft MycoLogic production module

Assumptions
100% of bags are harvested and sold
Employees cost 1.25x their hourly rate
Spent substrate can be sold for 80\$/1.5 yard
3 days of cleaning in between each harvest cycle
40ft container has a 400 5lb-bag capacity
Spent mushroom substrate has an equivalent density to sawdust
1st year has one lost cycle due to start up requirements
Module is operated continually for its lifespan (allowing for cleaning and repair)
Direct to customer distribution costs equal 20% of the total lbs harvested times the average hourly labor rate
Wholesale distribution costs equal 5% of the total lbs harvested times the average hourly labor rate
As total production increases, average \$ per lb decreases
Farm is assumed to be located in Gilmer County, Georgia
All calculations assume 5 lb bag of substrate
1 cubic foot of sawdust = 13.11 lbs
Pre-inoculated block = 6\$ per unit
Blocks are shipped in boxes of 8 @ \$31.61 per box
Wholesale has minimal Sales & Marketing expenses
Production remains consistent throughout entire year
Costing assumes 1st year of production with 15 modules built
Spawn costs \$11.10/bag and can inoculate 30 5lb bags
Substrate can be manufactured at a price of 1\$/bag plus 4 hours of labor/week
Mushrooms require 42 days per harvest plus 3 days of cleaning and repair