White Paper: Indoor Growing

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Indoor growing, also known as controlled environment agriculture (CEA), is going to transform the production, distribution and marketing of leafy greens and herbs over the next decade, as it has for vine crops such as tomatoes, cucumbers and peppers over the past 20-30 years (see Figure 1). We estimate that this transformation will require $10-$20 billion of capital investment in new growing facilities and will drive change throughout the supply chain by changing the way companies grow, process, and sell leafy greens. Indoor growing is a broad class of growing methods including traditional hydroponic greenhouses, fully automated pressurized greenhouses, multi-tiered "vertical" farming in warehouses that rely 100% on artificial light, and containerized vertical growing systems.

This white paper explores the case for indoor growing, technologies and growing methods, and their suitability for different crops.

1 Indoor growing is a complex family of technologies that can be integrated in different combinations for different crops. Microgreens, herbs, baby greens, and head lettuce are examples of crops grown indoors. The most fundamental choice is between vertical and greenhouse production.

Vertical farming refers to the class of growing methods that rely 100% on artificial light and is typically implemented in a traditional warehouse, converted industrial space (e.g., old mill buildings) or converted shipping containers. Crops are either grown in vertically stacked tiers (i.e., "bunk beds"), or on a vertical surface (i.e., "grow wall"). Vertical farms optimize land efficiency by stacking 4-8 growing beds on the same footprint,

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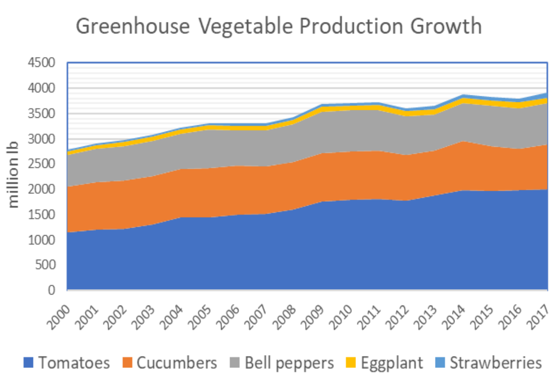

Figure 1: From 2000 to 2017 Greenhouse production grew 71% to 3.9 trillion lbs. (excluding greens production)

	Field Growing	Indoor Growing
Resource Consumption	▪ Occupies 200,000 acres in California[1] and 75,000 acres Arizona[2]. ▪ Consumes 224 billion gallons of water annually in California[3], equivalent to the water usage of 2.3 million households or enough to fill the Empire State Building 809 times.	▪ Greenhouses can be up to 40x more productive than field growing, and vertical farms, by stacking multiple tiers in an urban setting, can be 3-5x more productive than greenhouses. ▪ Uses 95% less water by eliminating evaporative loss and recycling irrigation water. In most parts of the country, greenhouses can operate entirely on rainwater captured off the greenhouse roof.
Greenhouse Gas Emissions	▪ Greens grown in California's Central Valley must be shipped 2,000-3,000 miles by truck to reach major Midwest and East Coast markets, generating a large carbon footprint. ▪ Requires significant diesel for farm equipment.	▪ Regional and local production cuts transportation and related carbon emissions by up to 90-95%. ▪ 10 acres of greenhouses in the Midwest will save 3,750 tons of CO_2 annually from trucking alone.
Chemical Use	▪ Lettuce is treated with an average of 13 pesticide applications per crop[4]. ▪ A USDA study found 52 different pesticide residues identified on greens at retail[5].	▪ Can eliminate the need for chemical pesticides by utilizing Integrated Pest Management (IPM), which relies on beneficial predatory insects to control harmful ones.
Food Waste	▪ Up to 30% of leafy greens are wasted between field loss, packhouse, transportation and spoilage at retail.	▪ Shelf life is dramatically extended by 14-21 days by not washing the product and it moving into the packhouse and establishing the cold chain before harvesting. ▪ Can virtually eliminate food waste due to automated systems eliminating harvest and packhouse losses. ▪ Transportation times are cut from 4-7 days to less than one day.
Food Safety	▪ The FDA reports field grown leafy greens are the top cause of food borne illness, accounting for nearly ¼ of all outbreaks[6]. There have been 30 major lettuce recalls in the U.S. since 2007.[7]	▪ Eliminates the two primary vectors for contamination: people and feces from birds and animals. Fully automated systems require very little human contact and growers wear protective clothing when they are inspecting the plants. The greenhouse protects the plants from bird and animal feces.
Labor	▪ Dependent upon low-cost migrant and often undocumented field labor.	▪ Automates low-wage jobs and creates high-paying light industrial green jobs.
Economics	▪ Production is seasonal and is subject to weather-driven volatility. ▪ With a fragmented supply chain, growers, packers/shippers, and distributors will continue to operate on narrow margins with a rising cost structure.	▪ Consistent year-round production virtually eliminates seasonality and volatility of supply. ▪ While the upfront capital costs of indoor growing are significant, margins and returns on capital can be very attractive.

and proponents of vertical farms point out their suitability for urban locations.

Vertical farms rely entirely on artificial light from LEDs, which allow growers to manipulate the color and wave lengths and develop a "light recipe" for each variety (see Figure 2). To the human eye, the lighting is typically in the blue or red spectrums and often appears pink.

Figure 2: vertical farm

Greenhouse farming has evolved in recent years. A traditional greenhouse relies on venting (letting cool air in at ground level and venting warmer air through the roof) and can at best only extend the growing season. By contrast, a modern state-of-the-art "over-pressure" greenhouse relies on sophisticated computer-controlled HVAC and air handling for environmental controls to maintain optimum temperature and humidity levels, allowing for year-round production (see Figure 3). Similar to vertical farms, modern greenhouses utilize lighting (often a combination of LED and Hi-pressure sodium). However, the lighting is supplemental to natural sunlight and used to extend the growing day (typically to 18 hours as plants need at least 6 hours of night to rest).

Figure 3: State-of-the-art greenhouse

> Greenhouses still use land approximately 40 times more efficiently than field grown.

Greenhouses require 3-4 times more land than a vertical farm and are consequently not well suited for dense urban locations. However, greenhouses still use land approximately 40 times more efficiently than field grown. Furthermore, the vast majority of leafy greens are sold through regional distribution centers in which rural locations are better suited.

Both vertical farms and modern greenhouses allow growers to control the growing environment by increasing CO_2 levels (typically to 3x atmospheric levels), which results in faster plant growth (see Figure 4 on the following page).

Both systems eliminate the requirement for chemical pesticides by isolating the crop from pests. While the isolation is not perfect – some pests will always get in – pests are controlled through Integrated Pest Management (IPM) which controls harmful insects by using beneficial ones. Growers hang sticky yellow cards

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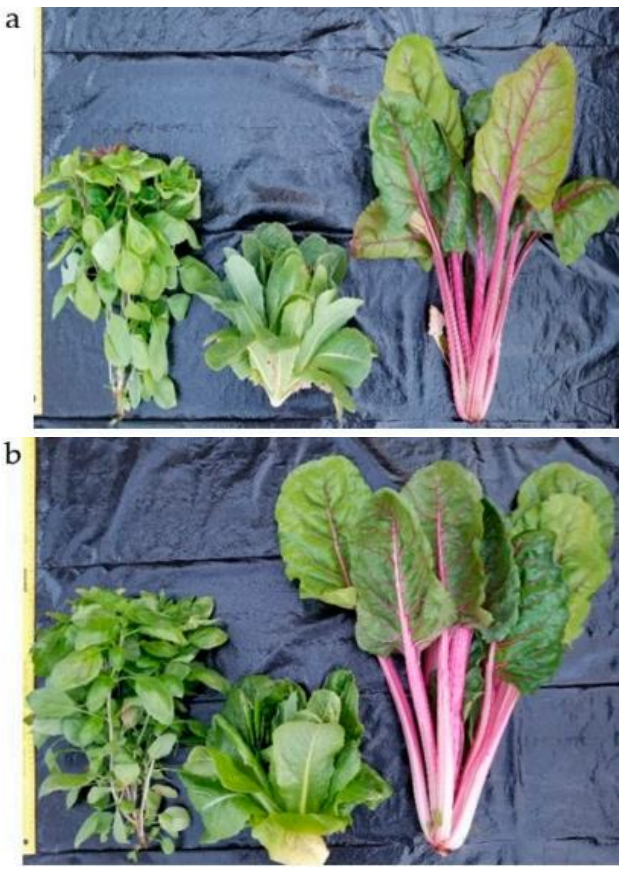


Figure 4: Basil, lettuce, and Swiss chard grown in (a) ambient and (b) supplemented CO2 conditions. Supplemented CO2 yielded increased weight by 24% on Basil, 25% on lettuce, and 40% on Swiss chard.

Waterbed systems are simple and inexpensive to build.

(essentially higher-tech versions of fly-strips) throughout the indoor farm. By examining the cards under microscopes, growers can identify early any harmful bugs that have entered the farm and can then release appropriate the "beneficial" (i.e., predator of the harmful species) to manage the population. When the harmful insects are all consumed, there is no food source for the beneficial and the beneficial population collapses. The key to IPM is constant diligence and early action before a population of harmful insects can take hold. If harmful insects are not caught early enough, it can cause the entire greenhouse to be shut down for an extended period and all the produce needs to be thrown out.

2 The second major choice to make in indoor farming for leafy greens is the growing system.

Traditional hydroponic systems use a waterbed. Plants sit on foam rafts with roots suspended in a pool of nutrient rich water. Waterbed systems are simple and inexpensive to build. The beds are typically constructed of cinder blocks and heavy gauge plastic sheets, and the rafts are rigid Styrofoam sheets with holes drilled in them. Many greenhouses are still being built with waterbed technologies.

Nutrient Film Technology (NFT), also known as "gutter systems," are a more advanced technology in which crops are grown in long plastic channels that resemble residential rain gutters. The gutter is filled with a growing medium (typically either peat or rock wool). Nutrients are delivered through a drip irrigation system that creates a film along the bottom of the gutter, which is absorbed by the growing medium watering the plants from below.

Less common growing systems include:

- **Aeroponics** is a new technology in which roots are irrigated in a mist. Despite significant venture investment (AeroFarms, the leading proponent of aeroponics, has raised $238 million to date and is still only producing limited quantities), aeroponics have not been proven to be profitable.[8]

- **Aquaponics** is the co-location of an indoor fish farm with a hydroponic growing system. The fish waste is processed to provide nutrients for the produce. Aquaponics are typically difficult to manage (balancing fish waste with nutrient needs) but can conceptually be used with either waterbeds or gutters.

The basic choices that will determine the economics of the business are (A) vertical vs. greenhouse and (B) waterbed vs. NFT.

The implementation of any indoor farm requires further choices around lighting, heating and cooling, environmental controls, and water treatment, among others. However, the basic choices that will determine the economics of the business are (A) vertical vs. greenhouse and (B) waterbed vs. NFT.

Comparative Economics

We have conviction that a fully automated gutter system in a state-of-the-art greenhouse for large-scale production of leafy greens provides superior economics to any vertical farm or to a greenhouse with waterbeds (see Figure 5).

Figure 5: Automated NFT System

Vertical farm technologies are still in development and have attracted $750 million+ of venture capital at technology company valuations. They are grabbing headlines, but they are not producing lettuce at commercial scale. Moreover, they are not economic yet, and we do not believe they will become so. Their estimates are based upon aggressive assumptions for the future upfront and operating cost of LEDs and on facility costs based upon orders-of-magnitude scale-up. These are aspirational projections.

Greenhouses, by contrast, are a proven system that can produce at commercial scale today.

Greenhouses, by contrast, are a proven system that can produce at commercial scale today. Even state-of-the-art overpressure greenhouses are a proven, off-the-shelf technology available from several credible suppliers in Europe. There are also multiple vendors with significant installed base for NFT gutter systems. Ceres estimates that a commercial-scale greenhouse with NFT gutter systems costs less than $9/lbs. to build and will produce for under $2.50/lbs., today.

Greenhouses can be regional, allowing for greater scale economies.

Figure 6: In red, a 300 radius from South Bend, IN

The biggest benefit of gutters is that the system can be fully automated.

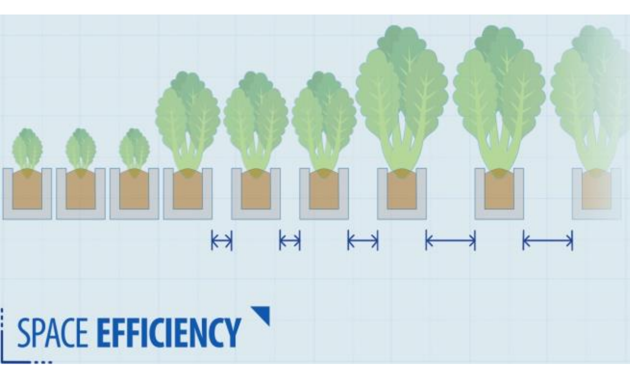


Figure 7: Gutters automatically space apart as the plants get larger to maximize very square inch of growing area.

While vertical farms may benefit from increasingly efficient LEDs (as will greenhouses), they still have a massive energy load. Vertical farming requires that either people or the product (and the water its growing in) are moved up and down repeatedly because automation is significantly more challenging. Additionally, vertical farms require significant air handling to move the air thorough the facility to all growing levels. All that vertical lifting and air handling requires energy.

The major benefit of vertical farms is their small overall footprint, making them suitable for densely populated urban locations. This is important in places such as Singapore, where land is prohibitively expensive or unavailable. However, the U.S. has ample land available for greenhouses outside of major urban areas and supply chains are built around large-scale distribution centers that are themselves outside of urban centers.

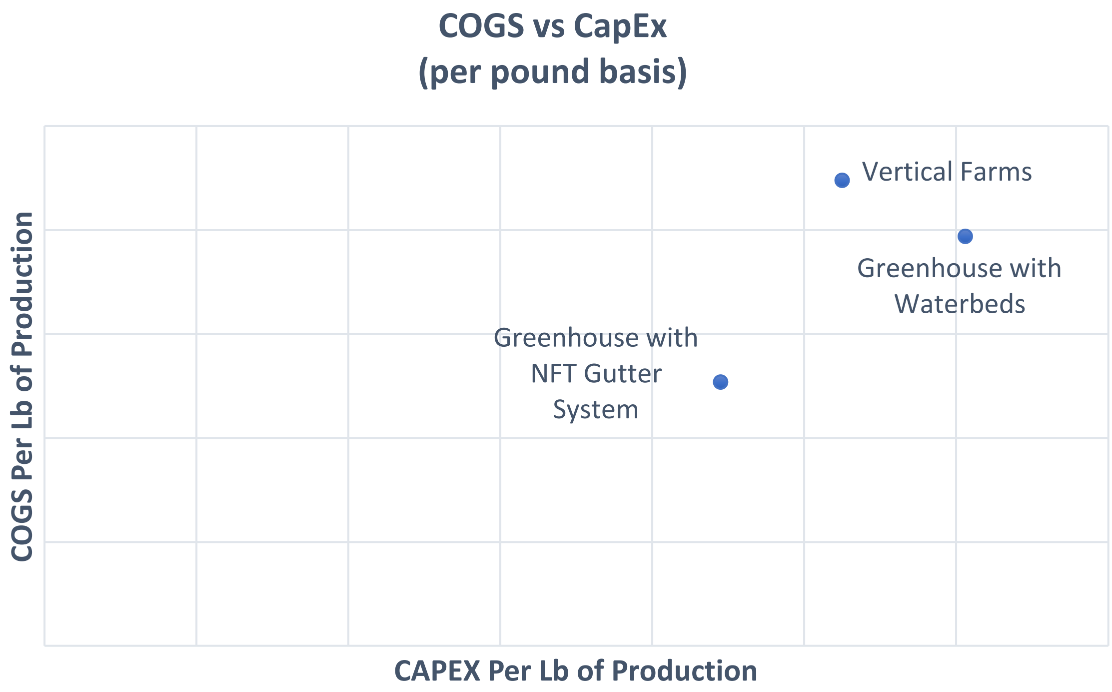
Greenhouses can be regional, allowing for greater scale economies, and can be sited for access to low-cost land and electricity and efficient logistics to deliver to retailers' distribution centers. A greenhouse the Midwest could serve 52 million people within a 300-mile radius (see figure 6), by delivering to 44 distribution centers serving 2,233 individual supermarkets.[9]

Gutter systems have two key advantages over waterbeds. First, gutters utilize greenhouse space more efficiently because the gutters can be next to each other when the plants are young and spread further apart as the plants grow and spread (see Figure 7). In a waterbed, the plant spacing is fixed – too far apart when young and typically too closely packed as the plants mature. The biggest benefit of gutters is that the system can be fully automated by integrating standard industrial components, with sophisticated software that determines which varieties to plant based upon the SKU mix scheduled for harvesting 26-30 days later. Gutters are automatically filled, seeded, moved through the greenhouse, harvested, and packaged. This automation results in major labor cost savings and improved food safety. The only people in an NFT greenhouse are the growers inspecting the crop and operators maintaining the equipment. No human hand needs to touch the greens until the consumer opens the package at home, as soon as the day after harvest. Through higher yields from more efficient use of growing space and reduced costs by eliminating field labor, NFT systems produce crops at lower costs than waterbeds.

Over-pressure greenhouses with NFT gutter systems are and will remain the low-cost solution for commercial-scale production of most leafy greens and deliver a superior product.

Conclusion

While vertical farms may find success in niche markets, we strongly believe that over-pressure greenhouses with NFT gutter systems are and will remain the low-cost solution for commercial-scale production of most leafy greens and deliver a superior product. This system uses proven technology with demonstrated capital and operating costs that are more attractive than waterbeds in a greenhouse, and substantially more attractive than the aspirational economics of vertical farms.



Sources

[1] California Agricultural Statistics Review
[2] Water and Irrigated Agriculture in Arizona
[3] California Agricultural Production and Irrigated Water Use
[4] Lettuce Chemical Treatment Guidelines
[5] What's on my food?
[6] The 10 Riskiest Foods in America
[7] PMA: Resolving Next Steps in Leafy Greens Food Safety
[8] AeroFarms Funding
[9] Population Radius