

WHITE PAPER / **POWERING A SHIFT IN AGRICULTURE**

CONFRONTING THE ENERGY CHALLENGES OF GROWING INDOOR AGRICULTURE

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The increasing application of indoor agriculture, driven by a movement to emphasize local food production as well as cannabis legalization, is applying new load pressures to the grid. Studies of the advantages of scenario combinations can help identify areas of potential efficiency gains.



INTRODUCTION

How and where we grow our food is changing radically. With the rise of the farm-to-table movement as well as an increase in the number of food recalls for various problems, more consumers are turning to local solutions for their food. These are changes that will have an impact on electricity use and grid design soon. Add cannabis legalization into the equation, and the country is now facing an almost nationwide agricultural transformation.

Agriculture in developed and some developing nations has been facing crucial change over the last decade. In traditional U.S. agriculture, produce travels an average of 1,400 miles from remote locations to urban centers. In Europe the distance is shorter but still significant. Shipping 1 ton of produce generates 0.25 ton of carbon dioxide (CO₂) alone. Traditionally, seasons and weather have dictated the when, where and what of planting. Areas became known for what they grow. For instance, California is known for winter strawberries, and Mexico is known for winter salad ingredients. Greenhouses were introduced to the food production process to bypass some of the adverse seasonal effects, while still allowing for the use of sunlight.

The latest agricultural revolution has two main drivers: indoor agriculture and the state legalization of cannabis.

DEFINING PLANT FACTORIES

A plant factory is a building (or in many cases a shipping container being used as a building) that is used to grow plants in a controlled environment. In most cases, the plant factory uses hydroponics to grow the plants with modern LED lighting.

Many plant factories use shelving units similar to what are used in warehouse stores like Home Depot or Sam's Club. In some cases, the shelving units may extend 40 feet into the air, with shelves of lettuce plants 12 to 18 inches apart and lighting installed on the bottom of the shelf above.

This agriculture revolution will change what is consumed, how fresh it is, and how much energy is required for production. Electric utilities nationwide have already started investigating some of the effects of these changes to the power grid. An effort to continue quantifying these changes is needed both in the short and long term to help utilities better prepare for this load increase.

THE COST OF PURCHASED ENERGY

A key reason that modern indoor plant factories for either produce or cannabis haven't yet made traditional greenhouses completely obsolete is the cost of purchased energy. A study comparing plant factories to greenhouses showed that for three locations studied, plant factories outperformed greenhouses in water use, CO₂ absorption and land use productivity, and total (purchased plus non-purchased) energy efficiency.

Even the most efficient greenhouse location studied — in Sweden, with artificial illumination — was outperformed by plant factories in terms of dry weight energy efficiency (472 kWh/kg versus 392 kWh/kg of dry weight produce). When purchased energy was compared, however, greenhouses excelled, with a requirement between 70-211 kWh/kg versus a plant factory requirement of 247 kWh/kg. The greenhouse requirement was lower because, even though greenhouses require lighting, the lighting comes in the form of sunlight, which does not contribute to the purchased energy amount.

The wide range in the greenhouse numbers is due to the environmental factors that greatly affect climate control requirements. This wide range ultimately means that for each location, whenever growing produce directly in the field is not possible, there are certain times of year when it would make sense to use a plant factory and other periods when a greenhouse would consume less energy. Determining these exact periods proved to be a worthwhile effort, as it can be easily reproduced in different locations.

A COMPARISON EXAMPLE

Suppose a lettuce (the most common produce used in the majority of studies) farmer in an urban center — Chicago, Illinois, is used for this exercise — has a large plot of land capable of fitting a lettuce field, a greenhouse and a plant factory next to a trendy restaurant. The field, greenhouse

and plant factory can be sized to yield the exact same amount of lettuce. Before building this three-in-one farm, there are a few questions the farmer would like answered:

1. When should each type of building be used to achieve the lowest annual energy consumption while maintaining a constant supply of lettuce throughout the year?
2. If using shipping containers to build the plant factory, how many would be needed to supply produce for an average-sized restaurant?
3. What would be the average power usage for each container in this Chicago-based plant factory?

The first question required four data sources:

- An earlier study that compared the energy consumption in greenhouses and plant factories in four cities — Atlanta, Georgia; Helena, Montana; Minneapolis, Minnesota; and Phoenix, Arizona. For Helena specifically, the study went one level deeper and made available not only yearly but also monthly energy consumption data.
- The planting calendar for lettuce in Chicago.
- The average temperature for every month in 2018 for Chicago and Helena.
- The average solar irradiance for every month in Chicago and Helena.

It also used four assumptions:

- Throughout the year, only one type of building is used at a time.
- Temperature is the only factor affecting heating and cooling energy consumption.
- Solar irradiance is the only factor affecting lighting energy consumption.

For each building type, the monthly energy consumption values (cooling, heating and lights) are calculated based on a linear trend using the two closest values of the data available for Helena. For example, to calculate the heating energy consumption in the Chicago greenhouse in May, when the average temperature is 61° F, the Helena greenhouse heating energy consumption in September (58° F average) would be averaged with June (64° F average).

Using the planting calendar for lettuce in Chicago, it was determined that field-grown lettuce is only an option in May, June, September and October; since field growing consumes barely any energy, it was the option chosen for these months. For July and August, field growing and greenhouses are not a viable option because these are the hottest months of the year, and the field and greenhouse options do not have a cooling system; for this period, the plant factory was chosen because it has cooling capability. For the other months, a comparison between the energy consumption in the Chicago greenhouse and the Chicago plant factory was necessary. See Figure 1 for the actual (Helena) and estimated (Chicago) energy consumption values for the greenhouse and Figure 2 for the actual (Helena) and estimated (Chicago) energy consumption values for the plant factory.

Comparing the total energy consumption values, it is determined that lettuce in Chicago should be:

- Field-grown in May, June, September and October.
- Greenhouse-grown in February, March and April.
- Plant factory-grown in January, July, August, November and December.

The second question, about the number of 40-by-8-foot shipping containers required to supply the produce needs for an average-sized U.S. restaurant, uses the following statistics:

- 10% of all produce is consumed in U.S. restaurants.
- 312.22 g of vegetables are consumed per person per day in the U.S.
- There are 328.4 million people in the U.S.
- There are 660,755 restaurants in the U.S.
- 48 lettuce heads per square meter is the yield of a plant factory.
- An average lettuce head weighs 800 g.
- The lettuce planting cycle lasts 90 days.
- The standard container size is 40 feet (12.192 m) by 8 feet (2.438 m), which equals 320 ft² (29.724 m²)

Note that lettuce is not the only vegetable used by a restaurant, but it provides an accurate estimate for a restaurant's produce needs. Using these statistics, the

Helena, MT - Greenhouse (Actual)						
Month	Average Temperature (F)	Solar Irradiance (GHI)	Energy Consumption-Cooling (kWh)	Energy Consumption-Heating (kWh)	Energy Consumption-Lights (kWh)	Energy Consumption-Total (kWh)
Jan	20	1.53	0	263,889	100,000	363,889
Feb	26	2.45	0	216,667	50,000	266,667
Mar	39	3.65	0	219,444	19,444	238,888
Apr	46	4.83	0	180,556	5,556	186,112
May	56	5.75	0	152,778	2,778	155,556
Jun	64	6.36	0	105,556	2,778	108,334
Jul	73	6.98	0	80,556	2,778	83,334
Aug	69	5.92	0	97,222	2,778	100,000
Sep	58	4.46	0	127,778	13,889	141,667
Oct	46	2.82	0	186,111	38,889	225,000
Nov	36	1.72	0	216,667	83,333	300,000
Dec	20	1.29	0	272,222	108,333	380,555
Chicago, IL - Greenhouse (Estimated)						
Month	Average Temperature (F)	Solar Irradiance (GHI)	Energy Consumption-Cooling (kWh)	Energy Consumption-Heating (kWh)	Energy Consumption-Lights (kWh)	Energy Consumption-Total (kWh)
Jan	26	1.78	0	216,667	80,593	297,260
Feb	33	2.56	0	216,667	46,697	263,364
Mar	40	3.63	0	213,889	19,712	233,601
Apr	48	4.79	0	175,000	6,457	181,457
May	61	5.51	0	116,667	3,503	120,170
Jun	72	6.16	0	84,723	2,778	87,501
Jul	76	6.18	0	68,055	2,778	70,833
Aug	75	5.27	0	72,222	4,227	76,449
Sep	70	4.44	0	93,055	14,026	107,081
Oct	56	2.9	0	152,778	37,015	189,793
Nov	41	1.89	0	208,333	75,571	283,904
Dec	28	1.45	0	216,667	102,778	319,445

FIGURE 1: Helena and Chicago greenhouse monthly energy consumption breakdown.

total weight of produce consumed in U.S. restaurants per day is calculated to be 10,253,304.8 kg. Dividing this by the number of U.S. restaurants yields 15.5 kg consumed in an average U.S. restaurant per day. Multiplying this by 90 days (lettuce planting cycle) totals the 1,396.6 kg of produce consumed in an average U.S. restaurant per lettuce planting cycle. If a standard container can produce 48 lettuce heads x 800 g x 29.724 m² = 1,141.4 kg, then, over the 90 days, if staggering the produce growth, the average U.S. restaurant would need 1.22 containers for its produce needs. In a scalable amount, a U.S. restaurant needs one produce container for every 12.7 kg of produce required daily.

Finally, the average amount of power required in Chicago by each of these container plant factories is calculated. The monthly energy consumption for the Chicago plant factory in Figure 2 adds up to 3,002.9 MWh annual energy consumption. Since this calculation used a 1,712 m² plant factory, scaling this number down to a standard container size results in 52.1 MWh annual energy consumption and 5.95 kW average power use. See Figure 3 for the monthly energy consumption of the plant factory, shipping container and average monthly power use of the shipping container.

Helena, MT - Plant Factory (Actual)						
Month	Average Temperature (F)	Solar Irradiance (GHI)	Energy Consumption-Cooling (kWh)	Energy Consumption-Heating (kWh)	Energy Consumption-Lights (kWh)	Energy Consumption-Total (kWh)
Jan	20	1.53	22,222	125,000	150,000	297,222
Feb	26	2.45	20,833	109,722	134,722	265,277
Mar	39	3.65	20,833	112,500	147,222	280,555
Apr	46	4.83	19,444	104,167	141,667	265,278
May	56	5.75	23,611	98,611	147,222	269,444
Jun	64	6.36	29,167	93,056	141,667	263,890
Jul	73	6.98	34,722	9,444	147,222	191,388
Aug	69	5.92	31,944	95,833	147,222	274,999
Sep	58	4.46	27,778	97,222	141,667	266,667
Oct	46	2.82	19,444	111,111	147,222	277,777
Nov	36	1.72	18,056	112,500	141,667	272,223
Dec	20	1.29	25,000	127,778	147,222	300,000
Chicago, IL - Plant Factory (Estimated)						
Month	Average Temperature (F)	Solar Irradiance (GHI)	Energy Consumption-Cooling (kWh)	Energy Consumption-Heating (kWh)	Energy Consumption-Lights (kWh)	Energy Consumption-Total (kWh)
Jan	26	1.78	20,833	109,722	150,000	280,555
Feb	33	2.56	18,889	111,667	134,722	265,278
Mar	40	3.63	20,635	111,310	147,222	279,167
Apr	48	4.79	20,277	103,056	141,667	265,000
May	61	5.51	28,473	95,139	147,222	270,834
Jun	72	6.16	34,028	31,041	141,667	206,736
Jul	76	6.18	36,806	0	147,222	184,028
Aug	75	5.27	36,111	0	147,222	183,333
Sep	70	4.44	32,639	74,236	141,667	248,542
Oct	56	2.9	23,611	98,611	147,222	269,444
Nov	41	1.89	20,436	110,119	141,667	272,222
Dec	28	1.45	20,278	110,278	147,222	277,778

FIGURE 2: Helena and Chicago plant factory monthly energy consumption breakdown.

PLANT FACTORY EFFICIENCY

The key to making plant factories more viable in terms of purchased energy is artificial lighting efficiency. The better the efficiency of the lighting system, the more that plant factories will be used, on a purely economic basis. The first study model uses LED lighting with 52% efficiency; the remaining 48% dissipates as heat, which is extracted by water cooling for optimal efficiency. Increasing this efficiency to 59% could reduce electricity use to 210 kWh/kg. Increasing the efficiency to 100% could reduce electricity use to 124 kWh/kg, depending on the location. Photovoltaic cells also could be used to generate part

of the required plant factory energy, but because of their small area, energy production on the roof of the structure would only account for 2.71% of the plant factory's total annual electricity requirement.

The farm-to-table and locavore (person whose diet consists only or principally of locally grown or produced food) movements will drive some uneconomic behavior because consumers will choose to pay extra for the locally grown produce. Fear of contamination also will help to drive uneconomic adoption of plant factories. Therefore, care must be taken with our assumptions. Even if lighting efficiencies aren't dramatically improved,

the number of plant factories might still increase substantially.

LOCATION AND PURPOSE CONSIDERATIONS

These findings lead to two important considerations regarding location and plant factory purpose. First, even though the benefits of solar energy in greenhouses exceed the need for climatization in all environments, greenhouses in most extreme weather locations are not viable without aggregating features of plant factories, such as artificial lighting and active heating or cooling.

As agriculture moves farther from an ideal climate for a plant species, the need to move first to a greenhouse and then to a plant factory becomes more urgent. This is a gradual shift from nearly natural to fully controlled interior production climate.

Second, plant factories do not always optimize for minimal energy or environmental footprint. Energy efficiency could be sacrificed in urban areas for a higher production per unit area, for example. A producer might also choose a less energy-efficient plant factory to avoid the risk of insufficient supply or contamination. Moreover, the closed production environment of a plant factory minimizes the risk of pathogen infiltration and the need for protective chemicals.

Much depends on the mission and purpose of the farm. Utilities in rapidly urbanizing territories and in regions with more moderate weather will need to be attentive to these trends and to the increase in artificial lighting efficiency. These farms have the potential to increase the load required for 1 kg of produce by 350%. Additionally, local income levels and attitudes can also shift production; one contamination event can trigger rapid menu changes in some restaurants and neighborhoods.

Month	Energy Consumption-Total (kWh)	Energy Consumption Container-Total (kWh)	Days in Month	Hours in Month	Average Power (kW) in Month
Jan	280,555	4,871.037862	31	744	6.55
Feb	265,278	4,605.796304	28	672	6.85
Mar	279,167	4,846.939199	31	744	6.51
Apr	265,000	4,600.969626	30	720	6.39
May	270,834	4,702.260407	31	744	6.32
Jun	206,736	3,589.381346	30	720	4.99
Jul	184,028	3,195.121654	31	744	4.29
Aug	183,333	3,183.05496	31	744	4.28
Sep	248,542	4,315.223369	30	720	5.99
Oct	269,444	4,678.127019	31	744	6.29
Nov	272,222	4,726.35907	30	720	6.56
Dec	277,778	4,822.823173	31	744	6.48

FIGURE 3: Monthly energy consumption for plant factory and container and average container power use.

ENERGY CONSUMPTION BREAKDOWN

In the same comparison study, the annual energy consumption for plant factories, plant factories with an economizer (used to save energy when outside conditions are suitable), greenhouses, and greenhouses with winter ventilation are compared in four U.S. cities: Atlanta, Helena, Minneapolis and Phoenix. Consumption is broken down by lighting, heating and ventilation/cooling. Every plant factory in the case studies required more total energy, more lighting and more ventilation/cooling than the greenhouses. Heating in Helena greenhouses and Minneapolis greenhouses with winter ventilation required more energy than their plant factory counterparts.

The more extreme differences in energy consumption happened in Phoenix and Helena. The Phoenix plant factory consumed 4,056 MWh per year, broken into 42.8% lighting, 37.9% heating and 19.3% ventilation/cooling. The greenhouse in this location consumed 347 MWh per year, broken into 40.3% lighting (mostly provided by the sun), 53.4% heating and 6.3% ventilation/cooling. The Helena plant factory with economizer consumed 3,303 MWh per year. This consumption

consisted of 52.7% lighting, 38.7% heating and 8.6% ventilation/cooling. The greenhouse with winter ventilation in this location consumed 2,574 MWh per year. This consumption consisted of 17.4% lighting (mostly provided by the sun), 81.6% heating and 1.0% ventilation/cooling. These results confirm that the predominance of plant factories lies in artificial lighting efficiency and that electric utilities need to be prepared for a 1.5- to 16-fold load increase (depending on location) for each new plant factory.

CANNABIS PRODUCTION

Indoor and outdoor cannabis production represents the other half of the current agricultural revolution. Due to weather conditions and indoor production costs in states where cannabis is legalized, about 90% of cannabis production in the U.S. is outdoors. In Tennessee, Kentucky, Hawaii and Washington, outdoor production is close to 100%. In Idaho and Oregon, the method of production is more balanced: 65% of cannabis in Idaho is produced outdoors; in Oregon, the percentage is 55%. Montana is at the other end of the spectrum, with only 20% outdoor production. Most states mandate a certain level of security on the growing operations, which can force growers inside regardless of the climate.

According to a 2014 study from the Northwest Power and Conservation Council, hundreds of producers in the state of Washington have been licensed to process cannabis. Growers of cannabis represent about 80-163 MW of new demand to the Northwest region's system. Since the estimated share of cannabis production in this region amounts to 21% (18% in Washington and 1% each in Oregon, Idaho and Montana), the total demand in the U.S. can be estimated to vary between 381 MW and 776 MW. This amount deserves some special attention from electric utilities, especially as more states legalize cannabis and demand continues to grow.

Even though only 10% of cannabis in the U.S. is grown indoors, the load profile for cannabis plant factories is far from flat, varying from 4 kW to 20 kW. Indoor growth requires 5,000 kWh/kg of cannabis, and lighting alone accounts for 80% of electricity use. Again, it is important to note how artificial lighting efficiency plays a crucial role in the balance between indoor and outdoor farms. Switching to more efficient lighting has the potential to generate demand savings of 23 MW by 2020 and 36 MW

by 2035 in the state of Washington. Many growers might consider switching to the more efficient LED lamps but are concerned about their cost.

Finally, it is important to characterize the load types in the different plant factory rooms required for cannabis production. The vegetation room requires a 1,000-watt metal-halide lamp for every two to eight plants and needs the lamps to be on for at least 18 hours per day. The flowering room requires a 1,000-watt high-pressure sodium adjustable ballast lamp for every two to three plants and needs to be on for 12 hours and off for 12 hours. A separate HVAC with temperature and humidity set points is required for each room in addition to an air conditioning mini split for every 1,000 square feet.

CONCLUSION

The efforts to characterize these relatively new types of load need to continue nationwide to make estimates more accurate. From a utility's perspective, these loads can vary not only in average load size, but also in load profiles. The main similarity in all plant factories is the relatively high load percentage required for artificial lighting. If lighting efficiency can be increased by at least 7% or 8%, a major shift from greenhouses to plant factories would be expected, and most U.S. consumers might soon be living directly above or below their source of produce.

BIOGRAPHIES

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