ACEEE
American Council for an Energy-Efficient Economy

*Emerging Opportunities Series*

# Controlled Environment Agriculture

A variety of horticultural products are grown indoors, either in greenhouses or, increasingly, in fully enclosed buildings. Indoor agriculture—or controlled environment agriculture (CEA)—is an energy-intensive endeavor. Cultivators must create the optimal growing conditions for a commercial crop, using artificial lighting, heating, cooling, and dehumidification to mimic the ideal outdoor environment favored by each plant.

As production ramps up, we are seeing increased interest in limiting the energy used to grow crops indoors. Growers, facility designers, equipment manufacturers, and efficiency program administrators are exploring opportunities to save energy and water and improve the sustainability of the industry.

This brief explores technical advances as well as policy and program options to reduce energy use in this expanding market sector.

## *The Opportunity*

Indoor agriculture is experiencing a surge of interest and investment in North America. The 2017 market value for the industry was estimated at $47 billion with a compound annual growth rate of 3.4% estimated for the 2018–2023 period.[1] Reasons for this growth include

- Growing consumer interest in year-round access to a wider variety of locally sourced food and flowers
- Concerns about food security and safety
- Expansion of legal markets for medical- and recreational-use cannabis

Today's CEA facilities produce primarily herbs, microgreens and lettuces, tomatoes, berries, and flowers. These crops are in demand year round, and they tend to command higher prices and have shorter shelf lives than other horticultural products. By moving production indoors, growers can produce multiple crops in a single year. A significant portion of cannabis cultivation also occurs in CEA facilities, in part due to local zoning and other ordinances that limit or prohibit outdoor cultivation. In addition, the lack of interstate commerce in cannabis products forces some growers to operate in states where the outdoor climate is not well suited for cannabis production.

CEA growers face a number of barriers. Respondents to a 2017 survey identified access to capital as their number one challenge.[2] While this survey did not include cannabis growers, financing is a critical issue for them as well and is exacerbated by federal limitations on banking for the cannabis industry. Another major challenge that respondents identified was building-related issues like pest control and management of environmental conditions.

High energy costs are also a barrier to success for CEA businesses. Heating, ventilation, and air-conditioning (HVAC), lighting, and dehumidification represent the largest end uses in these facilities. According to one estimate, up to 60% of a greenhouse or indoor cultivation facility's costs go to energy, with lighting accounting for roughly one-half of energy use.[3] The Electric Power Research Institute (EPRI) estimates that the typical indoor container farm consumes around 45 megawatt-hours (MWh) per year. More production-intensive vertical farms may consume between 8,700 and 70,000 MWh each year depending on the crop and size of the facility.[4]

The energy intensity of indoor horticulture has surprised many state and local policymakers, regulators, and efficiency program administrators. States that have legalized recreational cannabis use have experienced especially rapid growth in electricity demand. Xcel Energy reports that 50% of load growth in Denver since 2013 is attributable to cannabis production, which now accounts for 4% of the city's electricity consumption.[5] In Washington, Seattle City Light reports a 3% growth in electric demand, stemming from legalization.[6] The energy intensity of indoor farms varies depending on crop and cultivation method, so the energy and cost profile of individual farms can differ significantly as can the overall impact on local or regional demand growth.

Vertical farm: Aero Farm, Newark, New Jersey

**Shenandoah Growers Uses LEDs to Improve Energy Efficiency by 50%**

As the largest retail grower of organic herbs in the United States, Shenandoah Growers has built new greenhouse and vertical farm facilities as its business has expanded. The Virginia-based company is using LED lighting systems in its new facilities with impressive results for the company. Herbs are propagated year round in state-of-the-art vertical farms and then transplanted to greenhouses until ready to harvest. The company has worked with Fluence Bioengineering, a lighting manufacturer specializing in LED systems for horticultural applications. The LED system has increased lighting energy efficiency by 50% (compared to the company's greenhouses that use high pressure sodium lighting) while achieving a 25% increase in crop production. The shift to vertical farming has reduced water and fertilizer use by 60%.

Full case study available at **fluence.science/innovator-spotlight/shenandoah-growers**.

## *Savings Potential*

Several new technologies and cultivation strategies can improve the energy efficiency and overall sustainability of indoor horticulture. Detailed energy use data are limited, but case studies from facilities around the country highlight the opportunities for savings.

### *Lighting*

Lighting is critical in CEA; the final product depends on it. CEA facilities have traditionally relied on high-intensity discharge (HID) light sources—high-pressure sodium (HPS) and metal halide—with some use of fluorescent lighting. HPS is the most common type of lighting in indoor farms and supplemental lighting in greenhouses, but light-emitting diode (LED) technology is making inroads, particularly in vertical, or stacked, farms. Cooler-running LEDs can be placed much closer to plants without causing damage, allowing growers to increase cultivation space without expanding the overall footprint of their facility.

While LEDs offer attractive energy and operational savings (e.g., 10-year lifetime versus 1 year for HPS lamps), concerns over potential negative impacts on product quality and yield have left many growers reluctant to adopt the technology. LEDs also require a number of adjustments to a grower's long-standing farming practice. Additional research demonstrating best practice in LED lighting for a variety of plants can help address these concerns and show growers the full range of benefits.

Research is demonstrating the ways LEDs can be tuned to provide a variety of "light recipes" that optimize lighting intensity, spectrum, and hours of illumination to get the desired traits from each crop. One grower in Cincinnati is using different light recipes to produce a sweeter basil for grocery customers and a spicier version for chefs, all from the same seed stock.[7]

The US Department of Energy (DOE) estimates that lighting in CEA facilities consumed 5.9 terawatt-hours (TWh) of electricity in 2017. A complete shift to LED would reduce this to 3.6 TWh, a savings of 40%.[8] Savings vary by type of facility: 10% in vertical farms (where LEDs already account for roughly two thirds of lighting), 29% in greenhouses (where operational hours are lowest), and 41% in nonstacked indoor farms.[9] Findings from case studies confirm these results.

### *HVAC and Dehumidification*

The HVAC system in a CEA facility must maintain the proper temperature, humidity, airflow, and carbon dioxide ($CO_2$) levels for optimal plant growth and control of mold, mildew, and other pests that can damage or ruin crops. Each facility must have the flexibility to move plants or alter conditions to match the plants' changing needs over the course of the day and throughout the growth cycle. Facility designers and equipment manufacturers work closely with growers to design the sophisticated systems needed to ensure optimal conditions at the plant level, not just overall ambient conditions that are generally acceptable for buildings.

Opportunities for improved HVAC efficiency in CEA facilities include

- High-efficiency, variable-speed rooftop units
- Chilled-water systems
- Integrated systems designed to provide advanced cooling and dehumidification
- High-efficiency free-standing ductless dehumidification units
- Elimination of electric reheat in favor of hot gas reheat and/or other heat recovery technologies
- Creating opportunities for natural passive ventilation where appropriate
- Addressing changes in HVAC demand that come with conversion to LEDs

HVAC is the second-highest energy use in most CEA facilities and can account for 25%–50% of their energy use depending on location, facility type, and crops grown.

### *Other Savings Opportunities*

Other equipment common to CEA facilities offers additional opportunities for energy savings, but limited research makes it difficult to characterize and prioritize these options.

- $CO_2$ injection increases yields for many crops. $CO_2$ can be purchased in containers or created using gas-fired equipment. Co-location with electricity generation or industrial facilities that produce $CO_2$ can provide access to low-cost $CO_2$ and eliminate the need for onsite gas use or transport and delivery of $CO_2$.[10]
- Ceiling fans used throughout some cultivation facilities ensure adequate air flow across the plants.
- Air filtration systems remove impurities and reduce the risk of mold, mildew, and other contaminants that can reduce yield.
- Odor elimination systems counter the strong smell from cannabis production, which may be classified as a nuisance, particularly in urban settings.
- Processing energy loads may be required for drying and packaging of crops.

### *Other Benefits of Efficiency Investments*

When determining the cost effectiveness of high-efficiency design or efficiency upgrades in CEA facilities, the multiple benefits of the investments must be considered. Given the tight profit margins for many crops, any investments that can increase yield, reduce operating costs, and improve overall productivity are attractive to growers. Growers may also be able to take advantage of lower nighttime electricity rates by scheduling the light-intensive cycles at night and the dark "nighttime" cycles to coincide with higher-cost peak-pricing periods.

**Nonstacked indoor farm: Eco Firma Farms, Canby, Oregon**

**Eco Firma Farms Showcases Best Practices in Efficient Cannabis Production**

Eco Firma Farms operates a 4,800-square-foot indoor cannabis cultivation facility in Canby, Oregon. While expanding its business to shift from medical to recreational production, the company converted to LED lighting to reduce production costs. They reduced lighting energy use by 41% and lowered maintenance and disposal costs. The conversion to LED has also allowed the introduction of a two-tiered growing environment—increasing production without increasing the facility footprint—and lowered cooling demand. Eco Firma upgraded its HVAC systems in conjunction with the LED conversion, opting to install three-coil ground-mounted rooftop air-conditioning units with variable-speed drives, a hot-gas reheat coil, and advanced temperature, humidity, and $CO_2$ controls. The new system has reduced HVAC energy use by 30%.

The lighting and HVAC projects cost $232,564. Cash incentives from the Energy Trust of Oregon offset $100,000 of the cost to Eco Firma. As a result of the upgrades, Eco Firma has cut its annual electricity costs by $63,000 and improved production efficiency to 1.3 grams per watt. The efficiency projects have reduced annual electricity use by more than 755,000 kilowatt-hours (kWh) and $CO_2$ emissions by 359 tons, with savings split almost evenly between lighting and HVAC. The company is buying wind power credits to cut its remaining electricity-based carbon emissions.

Full case study available at **www.energytrust.org/wp-content/uploads/2018/03/EcoFirma_CS.pdf**.

## *Tools and Resources*

In response to the growing markets for CEA products, research organizations and industry groups have introduced new tools and information resources to help growers identify high-efficiency products and understand the opportunities for efficiency improvements in their facilities. These tools are being adopted by program administrators and policymakers to support their efficiency initiatives.

In 2018, the DesignLights Consortium (DLC) finalized testing and performance requirements for horticultural lighting products. DLC maintains a list of qualified products (the QPL) that meet the minimum threshold established for energy-efficient LED lighting. Before a product can be listed, it must be tested to verify it meets performance claims included on the QPL. The DLC requires listed LED fixtures to meet a photosynthetic photon efficacy (PPE) of at least 1.9 mmol/J.* Products must also meet other performance and lifetime requirements established by the DLC.[11] As of April 2019, the horticultural QPL included 18 products from 5 manufacturers.

Another tool developed to support growers, program administrators, and others interested in the efficiency of cannabis cultivation facilities is the Cannabis PowerScore. Developed by Resource Innovation Institute, the PowerScore is a survey tool that allows cannabis cultivators and operators to benchmark their facility's energy performance (whether indoor, greenhouse, or outdoor) relative to others. The tool helps fill the gap in available data on energy consumption in cannabis facilities. To date, more than 250 cannabis cultivation facilities have submitted data to the PowerScore, with growers and operators reporting that the tool has helped them to understand and better manage their energy use. The initial version of the PowerScore was limited to electricity use; in 2019 the tool will be enhanced to incorporate other energy sources, water consumption, and carbon emissions. Similar tools could help the broader CEA industry understand and improve energy efficiency.

* Photosynthetic photon efficacy (PPE) is a measure of how efficiently a horticultural lighting system converts energy into photons of photosynthetically active radiation (light that falls between 400 and 700 nanometers, the range needed for photosynthesis). PPE is measured in micromoles per Joule (mmol/J).

## *Program Approaches*

Utilities and other efficiency program administrators across the United States and Canada are developing or expanding their offerings for CEA facilities. This has become a priority in jurisdictions with legal adult-use cannabis markets, where the rapid increase in cannabis cultivation can create a spike in energy consumption.

Efficiency programs are important in addressing the challenges and barriers to energy efficiency in CEA. Technical assistance and best practice guides can address grower reliance on long-standing, traditional cultivation practices and reluctance to adopt new technologies and approaches. Coupled with financial support, these initiatives can also overcome concerns over disruption to production cycles and perceived negative impacts on yields. Program incentives can help growers facing the unique capital constraints created by federal restrictions on banking services for cannabis businesses.

Custom programs have been the most common offering for CEA facilities to date. As more data on energy use in CEA facilities becomes available, programs can expand their offerings. In addition to rebates and incentives for efficiency, utilities should explore how demand-response programs and tailored rate structures can take advantage of the flexibility of indoor farms while meeting customer needs and utility objectives for load management.

### *Energy Trust of Oregon*

Energy Trust of Oregon (ETO) offers cannabis cultivators incentives for the installation of high-efficiency LED lighting and lighting controls. They also pay the full cost of technical studies to identify custom HVAC, insulation, and other energy efficiency improvements. ETO bases incentive calculations on estimated energy savings, providing $.25 per kWh of electricity and $2.00 per therm saved up to 50% of project costs.

For cannabis and other CEA facilities, ETO also offers cash rebates for select efficiency measures for greenhouses, including infrared (IR)/polyethylene greenhouse covers, greenhouse controllers, condensing unit heaters, under-bench heating equipment, and thermal curtains.

### *Independent Electricity System Operator, Ontario*

Growers in Ontario, Canada, can access incentives for energy efficiency retrofits and new construction projects through a program developed by the

**Greenhouse: Indoor Urban Farms, Chicago**

Independent Electricity System Operator (IESO). The program offers incentives for LED lighting of C$.10 per kWh of savings up to 50% of project costs. Incentives up to 50% of project costs are also available for installation of sensors, dimmers, high-efficiency fans, variable-frequency drives for irrigation pumps, building envelope improvements, and energy audits.

### *Sacramento Municipal Utility District*

Sacramento Municipal Utility District (SMUD) offers rebates of $300 for each high-efficiency LED fixture installed in indoor cultivation facilities. To qualify for the incentive, LED fixtures must meet the DLC horticultural lighting specification. Additional incentives are available for some types of lighting controls.

SMUD also offers custom incentives, calculated for each project, for the installation of high-efficiency air-conditioning and dehumidification equipment. SMUD extends their incentives to some extraction and manufacturing process equipment used in cultivation facilities, offering incentives of $.15 per kWh of electricity savings and $200 per kW of demand reduction. All incentive offerings are capped at 50% of overall project costs.

## *Policy Options*

Horticultural facilities are largely exempt from energy codes and other efficiency policies covering buildings and industry. While HVAC and lighting are the largest energy end uses, just as in many commercial buildings, these end uses are classified as "process loads" in cultivation facilities. As a result, they fall outside the scope of those energy loads regulated by code.*

State and local policymakers establishing new policies and regulations for the burgeoning recreational cannabis markets across the country are incorporating a range of energy efficiency and other sustainability policies. These policies can serve as pilots for policies to advance clean energy objectives across the full range of CEA facilities. Table 1 summarizes policies adopted for cannabis cultivation.

Cultivation facilities are typically exempt from local energy use disclosure ordinances targeted to commercial and multifamily buildings. For example, Denver's benchmarking and disclosure ordinance exempts buildings used primarily for industrial or agricultural purposes. This is a missed opportunity to provide growers and operators with valuable data on their energy use and address the data gaps that hinder policy and program development for CEA facilities. State and local policymakers are beginning to adopt and implement disclosure policies for cannabis cultivation facilities. For example, Massachusetts is working on final regulations to require cannabis growers to report their energy use through the Cannabis PowerScore. These policies could be expanded to other CEA facilities beyond cannabis.

**Table 1. Energy regulations for cannabis cultivation facilities**

| State | Relevant state regulators | Energy regulations | Notes |
|---|---|---|---|
| California | Department of Food and Agriculture (CalCannabis Licensing) | Energy use disclosure after 2022; electricity greenhouse gas (GHG) intensity mandates starting in 2023 | 20% tax revenue earmarked for restoring environmental damage from cultivation; utility incentives |
| Colorado | Local governments | Boulder County and City of Boulder: energy use reporting, renewable energy requirements, and disposal of e-waste at certified facility | Penalties support "Energy Impact Offset Fund" used to educate and encourage energy-related best practices in cultivation |
| Massachusetts | Cannabis Control Commission | Lighting power density, building envelope, and HVAC standards; demonstrated commitment to renewables and energy efficiency in application; energy use disclosure upon license renewal application | Optional "Energy and Environmental Leader" recognition for 100% onsite renewable energy generation; utility incentives for energy-efficient equipment |
| Oregon | Energy Trust of Oregon | Energy use forecast required; guidance and incentives for installation of energy-efficient equipment | Free technical services for energy projects, including energy use calculator; utility incentives |

Massachusetts is also taking the lead in establishing energy performance requirements for cannabis facilities. The regulations require cultivation facilities to meet ASHRAE building envelope standards for insulation, air tightness, and air barrier thresholds in accordance with state building energy codes. HVAC and dehumidification systems must comply with Massachusetts Building Code requirements. The state has also adopted lighting efficiency requirements of less than 36 watts per square foot of canopy and is working on a revision that would allow for compliance through demonstrated installation of lamps exceeding DLC minimum requirements for horticultural lighting.

* According to ASHRAE 90.1-2016, process loads are defined as "the load on a building resulting from the consumption or release of process energy." In turn, the standard defines process energy as "energy consumed in support of manufacturing, industrial, or commercial process other than conditioning spaces and maintaining comfort and amenities for the occupants of a building." In the case of lighting, ASHRAE 90.1 goes further, providing an exception to the lighting power allowances for "lighting specifically designed for the life support of nonhuman life forms."

# Notes


1 Mordor Intelligence, Indoor Farming Market (Hyderabad: Mordor Intelligence, 2019). www.mordorintelligence.com/industry-reports/indoor-farming-market.

2 Agrilyst, State of Indoor Farming 2017 (New York: Agrilyst, 2017). www.agrilyst.com/wp-content/uploads/2018/01/stateofindoorfarming-report-2017.pdf.

3 Merritt Melancon, "US (GA): $5 Million to Help Reduce Energy Costs of Indoor Farming," HortiDaily, September 11, 2018. www.hortidaily.com/article/45703/US-(GA)-$5-million-to-help-reduce-energy-costs-of-indoor-farming/.

4 EPRI (Electric Power Research Institute), Indoor Agriculture: A Utility, Water, Sustainability, Technology and Market Overview (Palo Alto: EPRI, 2018). www.epri.com/ - /pages/product/000000003002014056/?lang=en.

5 Grace Hood, "Nearly 4 Percent of Denver's Electricity Is Now Devoted to Marijuana," Colorado Public Radio News, February 19, 2018. www.cpr.org/news/story/nearly-4-percent-of-denver-s-electricity-is-now-devoted-to-marijuana.

6 Evergreen Economics, SDG&E Cannabis Agriculture Energy Demand Study (San Diego: San Diego Gas & Electric Company, 2016). www.calmac.org/publications/SDG%26E_Cannabis_Ag_Energy_Demand_Final_Report_071516ES.pdf.

7 Adrian Higgins, "The Cutting-Edge Technology That Will Change Farming," *Washington Post*, November 9, 2018. www.agweek.com/business/agriculture/4527042-cutting-edge-technology-will-change-farming.

8 DOE (Department of Energy), Energy Savings Potential of Solid-State Lighting in Horticultural Applications (Washington, DC: DOE, 2017). www.energy.gov/sites/prod/files/2017/12/f46/ssl_horticulture_dec2017.pdf.

9 Ibid.

10 Eugene Mohareb, Martin Heller, Paige Novak, Benjamin Goldstein, Xavier Fonoli, and Lutgarde Raskin, "Considerations for Reducing Food System Energy Demand While Scaling Up Urban Agriculture," Environmental Research Letters 12 (12), December 5, 2017. iopscience.iop.org/article/10.1088/1748-9326/aa889b/meta.

11 DesignLights Consortium, Testing and Reporting Requirements for LED-Based Horticultural Lighting, Version 1.1, effective March 6, 2019 (Medford, MA: DesignLights Consortium, 2019). www.designlights.org/default/assets/File/Horticultural/DLC_V1-1-Testing-Reporting-Requirements-Horticultural-Lighting.pdf.


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