Market Characterization of Indoor Agriculture (Non-Cannabis)

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EXECUTIVE SUMMARY

This report outlines the findings of a market characterization study for Controlled Environment Agriculture (CEA) in Southern California. The report findings are based on a combination of literature review and stakeholder interviews. This study was commissioned by Southern California Edison (SCE) to investigate a potential offering within its energy efficiency (EE) incentive programs. Interviews were conducted with various stakeholders from Investor Own Utilities (IOU), growers, associations, and vendors to document the current industry practices and existing market barriers in adopting EE techniques in Southern California. By understanding how and why industry stakeholders make decisions, the existing barriers are more distinctly defined, and solutions developed. The intent of this report is to assess the market to determine savings potential, how utility intervention strategies can help achieve that potential, and recommend a course of action.

The scope of this study involved the following components:

- Interviews with industry stakeholders: growers, IOUs, vendors, and associations.
- Analyses of industry norms, energy savings potentials, greenhouse gas reduction (GHG), and energy reduction potentials
- Recommendations of proposed incentive design
- Proposed next steps for increasing ICA participation in Utility Incentive Programs

The worldwide CEA industry has seen rapid growth over the past decade. Drivers such as extreme weather conditions, droughts, and fires have created an expansive and thriving market. Consumer demand for high quality, organically grown, and continuously available produce have further accelerated the advancement of indoor agriculture. The progression has been predominantly in European and Asian countries, although some Eastern U.S. states have seen new CEA facilities established in recent years. While California still has a strong traditional outdoor agriculture infrastructure, it is expected that CEA will expand there as well from greenhouses to fully indoor facilities. With this advancement of the industry on a global scale, growing techniques and technologies have improved and will continue to evolve with the market.

Stakeholder interviews identified a consistent market barrier of capital constraints when considering EE technologies. Traditional farming has a large advantage over CEA facilities in being far less energy intensive. While CEA facilities have lower water consumption, the additional cost from HVAC and lighting reduce their margins; thus, making investments challenging to their operations. This complexity also brings significant opportunity for energy savings. The challenge of balancing systems within a controlled environment opens the door for developing new technologies and holistic solutions to reduce energy consumption while improving quality and increasing yields. Stakeholders also shared their perspective on potential solutions such as streamlining the incentive process, providing education and training to growers and tailoring incentives for the ICA market. This report summarizes the state of the industry, interview results, future outlook, and recommended next steps.

ABBREVIATIONS AND ACRONYMS

AUMA	Adult Use of Marijuana Act
CEA	Controlled Environment Agriculture
DLI	Daily Light Integral
DWC	Deep Water Culture
DX	Direct Expansion
EE	Energy Efficiency
ERI	Energy Resource Integration
GHG	Greenhouse Gas
HID	High Intensity Discharge
HPS	High Pressure Sodium
HVAC	Heating, Ventilation, and Air Conditioning
HVACD	Heating, Ventilation, Air Conditioning, and Dehumidification
HVLS	High Volume Low Speed
IBC	International Building Code
ICA	Indoor Cannabis Agriculture
IECC	International Energy Conservation Code
IOU	Investor-Owned Utility
J	Joule
kPA	Kilopascal

LPD	Lighting Power Densities
MAUCRSA	Medicinal and Adult Use Cannabis Regulation and Safety Act
MH	Metal Halide
NFT	Nutrient Film Technique
PAR	Photosynthetically Active Radiation
PPE	Photosynthetic Photon Efficacy
PPF	Photosynthetic Photon Flux
PPFD	Photosynthetic Photon Flux Density
SB	Senate Bill
SCE	Southern California Edison
THC	Tetrahydrocannabinol
UA	Urban Agriculture
UAIZ	Urban Agriculture Incentive Zones Act
VPD	Vapor Pressure Deficit/Differential

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INTRODUCTION

The benefits of growing agriculture indoors are becoming more recognizable by both consumers and investors. Primary benefits include improved product quality, increased production per plant, and less water consumption. Despite the innovative advances to improving the quality and cost-effectiveness of indoor agriculture, also known as Controlled Environment Agriculture (CEA) or Controlled Environment Horticulture, the sector is still an emerging market within the United States. It is projected that global indoor agriculture market will grow from 2.3 Billion USD in 2020 to 6.0 Billion USD by 2025 with the USA's market following similar growth trends.

The recent growth of indoor agriculture for food production has stimulated interest from utilities in understanding the current status of the CEA market. Of a particular concern is the future growth in energy usage for this market. The primary energy input for most of these facilities is lighting. Lighting power densities are in the order of 10-35 W/ft2, which typically accounts for between 30% to 50% of energy usage in CEA facilities. When discussing and comparing lighting fixtures for indoor agriculture facilities, it requires an understanding of lighting technology concepts specific to horticultural lighting.

LED lighting technologies have also been increasing in global popularity for all forms of CEA facilities with estimates to be the global standard by the next decade. The adoption of LEDs for CEA facilities within the USA have also been following this trend with LED market share estimates varying between 25% to 40% depending on the study.

However, LED fixtures have been slow to gain traction in recent years because of the high up-front cost. An LED fixture producing similar light output to a 1000W HPS fixture can cost 3-4 times as much as the HPS fixture. In addition to higher cost, LED fixtures face a negative perception within the industry. Several early experiments with LED fixtures in indoor agriculture were conducted when LED technology performance was unable to meet growers' expectations. Thus, many in the industry still consider LEDs to be inferior to traditional lighting technologies, despite advances in light quality made in the LED space.

For existing CEA facilities, the primary barrier to EE implementation is financial. Of the interviewed growers, all cited capital limitations as the primary barrier for not implementing any EE technologies. While each facility's profitability varies, on average the profit margins were noted to be too thin to invest any capital. Because of this, financial incentives for EE technologies would have a significant impact on technology adoption if they were able to reduce payback periods to meet grower requirements.

The purpose of this paper is to identify multiple potential solutions, emerging technologies, and methods that SCE can adopt to improve their relationship, participation, and overall energy savings from CEA customers. It is recommended that SCE perform an internal audit of their CEA customers to develop a detailed characterization of the sector before proposing new incentive offerings to help characterize standard practices and growing techniques used throughout the SCE territory.

BACKGROUND

INDOOR AGRICULTURE HISTORY

Despite the innovative advances to improving the quality and cost-effectiveness of indoor agriculture, also known as Controlled Environment Agriculture (CEA) or Controlled Environment Horticulture, the sector is still an emerging market within the United States. It is projected that global indoor agriculture market will grow from 2.3 Billion USD in 2020 to 6.0 Billion USD by 2025[1] with the USA's market following similar growth trends.

With the increased adoption of Greenhouses in the 20th century, scientists around the world began testing various methods to improve their crop quantity and quality through artificial climate control. As the world's population increased and urban density grew, many countries started to explore methods to grow closer to populated areas and year-round. This need for year-round vegetables lead to the start of the modern indoor agriculture stemming from many Asian countries such as Japan in the 1980s[2].

Due to the abundance of farmland within the United States, the use of indoor agriculture was not adopted as readily as in other countries. It was not until NASA funded research on growing plants within controlled environments that lead to the interest in indoor growing within the United States. This led to many government-funded facilities for research on indoor horticulture techniques, such as hydroponics, and plant health in the 1970s[3]. This wave of research included Geniponics research into growing plants inside submarines[4]. During this time, many Asian countries began building and using indoor agriculture facilities to meet their countries food supply needs with Japan being an early adopter.

In the late 1970s and 1980s, there were a few indoor growing facilities in the United States, however they were not successful due to the cost of electricity, and technology limitations for growing leafy greens and vegetables. During the 1990s, Japan developed an indoor horticulture industry around a "Plant Factory" design, which started to innovate by using different growing styles and techniques which ultimately lead to modern vertical farming[4]. The next major innovation within indoor farming was research and development in using LEDs for indoor horticulture, with application-based testing in research starting in the 2000s. There have been many innovations within the LED technologies within the past 15 years from improving efficiency, controlling of the light spectrum, and improving fixture longevity. With these developments in indoor agriculture, the sector has grown to a $47 billion dollar market in the USA that is projected to continue growing each year[5].

BENEFITS OF GROWING INDOORS

There are many factors that are credited with the increased adoption of indoor agriculture around the world. Some of the contributing factors are consumer needs, environmental impacts, greenhouse gas (GHG) reduction, and community benefits that this sector has

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[1] https://www.marketsandmarkets.com/Market-Reports/horticulture-lighting-market-131559722.html

2 http://agfundernews.com/wp-content/uploads/2016/01/The-Rise-of-Asias-Indoor-Agriculture-Industry-White-Paper_FinalProtected.pdf
3 https://urbanagnews.com/blog/education/early-history-of-indoor-agriculture-associated-technology-development/
4 Landscape Change and Resource Utilization in East Asia: Perspectives from Environmental History. (2018). United Kingdom: Taylor & Francis. Chapter "Origins of Artificial Light Type of Plant Factory"
5 https://askwonder.com/research/indoor-agriculture-us-vacg8sr8c#:~:text=The%20US'%202018%20market%20size,3.4%25%20between%202018%20and%202023.

produced. Within the United States market, indoor agriculture has seen a constant and steady increase over the past few decades. In addition to the above factors, the United States market has experienced a consistent increase in the organic food market which aligns with the increase in adoption of indoor agriculture[6]. All these market factors are supported by the multiple benefits of indoor agriculture that also stimulated the market in the United States.

Over the past decade in California, there have been multiple droughts that have directly affected the agriculture sector and have resulted in policy and regulation changes to water consumption. With the use of indoor agriculture, water consumption has the ability to be reduced by a least 10% to 50% with some vertical farming facilities reaching 90% water reduction[7].

Along with less water consumption an indoor grower can plant and harvest multiple times per year and up to 5-8 harvest cycles in some cases. Thus, producing higher annual crop yields. This is possible since indoor agriculture is not dependent on seasonal weather, hostile climates, pests, or overall climate change. This independence from outside weather or climates allows for year-round production[8].

Depending on the crop grown, indoor agriculture can greatly reduce the required human interaction with the crop. This is made possible by the extensive use of technology and automation. Crops grown indoors in a closed loop system are isolated from the usual contaminants that outdoor crops are susceptible to. For example, indoor agriculture farms do not typically require pesticides or herbicides to be used in order to manage pests and weeds. Additionally, risk of contamination with e-coli or other food-based bacteria is much lower since there is nearly no risk of indirect contact with fecal matter from nearby farmlands. There is a significant reduction in fertilizer used, up to 40% as there are less losses due to irrigation and other environmental conditions[5].

Unlike greenhouses, fully enclosed indoor agriculture facilities can be directly located within urban or residential areas. This geographic benefit has multiple community and social-economic benefit for areas where fresh produce is not as easily accessible. The crops can be locally grown in a busy city near its final destination instead of shipped from the other side of the country. This reduces emissions, consequently reducing GHG and improving produce quality. The cost and energy expenditure of gasoline/diesel-fueled equipment needed for planting, harvesting, plowing, and transporting produce is dramatically reduced[7]. This also eliminates damage to outdoor fields due to soil erosion or nutrient depletion concerns caused by misuse or pollution. Additionally, indoor agriculture uses significantly less land than what is typically used for outdoor agriculture for the same or equivalent production amount, depending on the crops grown and growing techniques applied[7].

TECHNOLOGIES AND FARMING TECHNIQUES

FARMING TECHNIQUES

Within the indoor agriculture sector, the five most common farming techniques are hydroponics, aquaponics, aeroponics, soil-based, and hybrid systems. While there are other

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[6] There is contention over the classifications of indoor grown hydroponics as organically certified. There have been multiple petitions and legal action against the USDA by various associations to revoke the ability for hydroponics/biponics to received organic certification. At this time in Oct 2020, hydroponics can be organically certified.

[7] https://scholarworks.uark.edu/cgi/viewcontent.cgi?article=1067&context=jflp

[8] https://artemisag.com/wp-content/uploads/2019/06/stateofindoorfarming-report-2017.pdf

system types outside these common five, they typically share commonalities or are emerging technologies, which still require further research for market adoption.

Aeroponics grow crops by suspending the plant roots in air, and the roots are misted with nutrient filled solution. The benefits of this growing method include improved plant health due to the plant's access to atmospheric levels of gases, pest control, and significant reduction in water consumption compared to other water based growing methods. However, these facilities are typically the costliest to construct and account for a smaller percent of the market[9].

FIGURE 1. AEROPONICS FARMING TECHNIQUE

Hydroponic systems use a common water system to allow the plants roots to be in direct contact with the nutrient rich water. There are multiple sub-types of hydroponics, including Deep Water Culture (DWC), Nutrient Film Technique (NFT), flood & drain, and other direct water to root systems. The benefits of hydroponics include increased control of plant nutrients and pH, increased production density, and increased plant yields.

FIGURE 2. HYDROPONIC FARMING TECHNIQUE

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[9] 2019 Global CEA Census by Autogrow & Agritecture Consulting

Aquaponics is very similar to hydroponic growing with the primary difference is the use of fish to fertilize the water. The fertilized water is consumed by the plants with fresh water returning to the fish. The benefits of aquaponics include less chemical, and fertilizers used, reduce water consumption compared to hydroponics, and the ability to harvest fish.

FIGURE 3. AQUAPONICS FARMING TECHNIQUE

Soil based indoor agriculture can be viewed as the basic or standard method of growing plants in containers or pots. The main benefit of soil-based indoor agriculture is the ease of production, with fewer fluctuations and control points, since it is closest to traditional farming techniques which are well documented. Additionally, some crops perform better when grown in soil over soilless media.

FIGURE 4. SOIL BASED FARMING TECHNIQUE

Hybrid systems utilize two or more of the different growing techniques within an indoor facility. The combination of techniques varies based on the crops being produced, building, and crop yield potential. The benefits of a hybrid system are the ability to capitalize on strengths of each growing technique with little to no impacts on the product.

FIGURE 5. HYBRID SYSTEM FARMING TECHNIQUE

BUILDING TYPES AND CONSTRUCTIONS

There are different types of buildings used for indoor agriculture or CEA. The most abundant of which are greenhouses. Greenhouses are typically structures made of glass or other translucent material that allows for natural light to transmit inside but covers the crop from other elements such wind and rain. Depending on the outside climate, the greenhouses use equipment to create an artificial environment inside the structure such as heating or cooling and artificial lighting to simulate longer "days" or sunlight. While greenhouses fit the definition of and are widely considered to be a subset of CEA, for the remainder of this paper, "Indoor Agriculture" and "CEA" will refer to fully enclosed, artificially lit, and climate-controlled facilities not including greenhouses.

Indoor agriculture facilities are typically established as either new construction or major renovation of an existing warehouse. Buildings can vary in size from a small, single-story warehouse to a commercial building several football fields wide or multiple stories tall. The size and configuration can be endless depending on the land and structure availability in the local area.

An emerging branch of CEA are "pre-retrofitted" freight containers. The start-up cost for these compact units typically starts at around $33,000 for the smallest containers (80 ft^2), equating to a cost of approximately $412/ft^2. Full-sized containers (320 ft^2) typically start at $79,000, equating to a cost of $246/ft ft^2.

The units are pre-built and modified (with light boxes, growing racks and irrigation system) for CEA, and all the necessary equipment is self-contained in the converted shipping freight containers. The containers can be mobilized to just about anywhere and have a compact footprint in which the "farm" is ready to operate upon arrival. The start-up cost can be lower than a typical greenhouse or CEA building. But the operational costs can be higher when balanced with the production volume possible in such a smaller square footage (32 ft^2)[10].

In any of the various techniques described above, the plants' orientation within the facility also varies based on the available space, plant size, and growing technique. There are two

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[10] "Which One is Right For You?," Freight Farms, 29 June 2016. [Online]. Available: https://www.freightfarms.com/blog/different-indoor-farming-methods.

main growing configurations[11] for indoor agriculture including non-stacked and vertical farming.

NON-STACKED

This growing configuration, also called High Intensity Sole-Source Farming, is defined as growing plants in a single layer on the floor with high intensity electric lighting with no sunlight. This configuration has the plants in a single layer either on the ground, raised bed, water table, or other horizontal orientation.

VERTICAL FARMING

This configuration of growing plants uses a vertical tier system to increase the density of plants in a given area. Also called stacked farming, plants grown in this configuration consist of a least two layers or shelves with individual or common lighting source. Vertical farm takes advantage of the available vertical height of the CEA facility to improve crop yields.

With any of the CEA methods described above, challenges are faced in balancing cost, technology, and production. Fully enclosed CEA uses much more equipment than greenhouses since they are fully reliant on artificial lighting and climate control. The energy usage or draw on the local electrical grid because of the indoor lighting and climate control is all managed and provided artificially by some or all of the following technologies listed in **Table 1**.

TABLE 1. DESCRIPTION OF EQUIPMENT AND TECHNOLOGY USED FOR INDOOR AGRICULTURE EQUIPMENT

TECHNOLOGY TYPE	DESCRIPTION AND KEY FACTORS
Sensors	In order to monitor the climate, sensors such as temperature, humidity, soil moisture, and many others are deployed. Light sensors are used primarily as photosensors for greenhouses but can also be used to determine level of light levels in a growing area. While all these sensors can be integrated into a control system, some measurements are performed manually by the grower.
Hygrometers	To monitor the humidity levels in the growing area.
HVAC systems	• Technologies used vary from Heat Pumps, Direct Expansion (DX) package units, DX Mini-Splits, and Hydronic Chiller Systems • Dehumidification is typically achieved through portable dehumidifiers or at the air distribution level if available. • Due to improper sizing, facilities experience high loading and long run times. • With an air filtration of MERV 14 or greater, outside air can be used without introducing outside contaminants. • CEA facilities are commonly closed-ventilation systems employing HID lights and the grow rooms are cooling-dominated environments.
Internet of things (IoT)	• Using artificial intelligence, machine learning, and other advanced algorithms to assist growers in their operations. • Mobile device control capabilities. In the future could employ grid connectivity at the equipment level and enable responsiveness to regional grid impact events.
Environmental Controllers	Controllers use input data from sensors and cameras to modulate the HVAC, Lighting, water, and other systems. CEA facilities may develop

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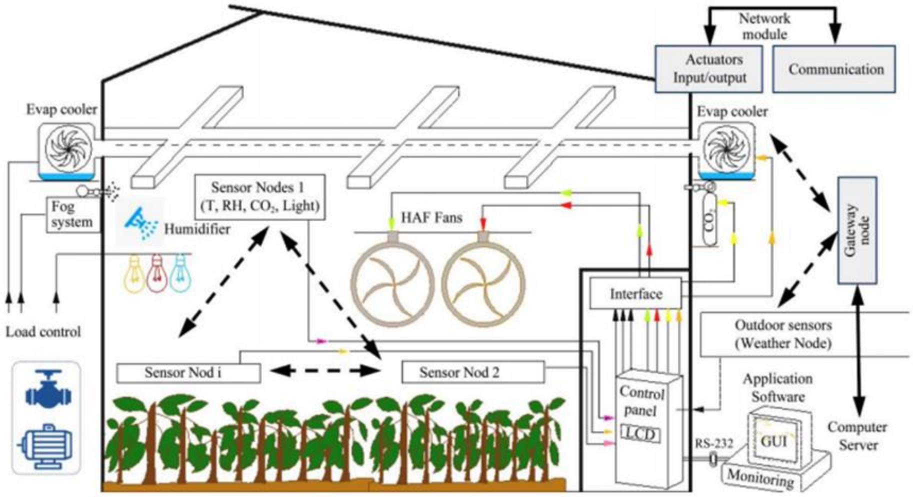
[11] Energy Saving Potential of SSL in Agricultural Applications. DOE 2020

TECHNOLOGY TYPE	DESCRIPTION AND KEY FACTORS
(Hardware and Software)	homemade/customized systems, work with a controls vendor, or develop proprietary sensor and controls systems in partnership with universities.
Automation	• Used for cloning, growing, harvesting, production and to replace human labor/contact.
Artificial Lighting	• Historically incandescent, fluorescent, and high-intensity discharge (HID) lamps such as high-pressure sodium (HPS) lamps were used. • A photoperiod is the number of hours per 24-hour day in which plants are exposed to light. Depending on the crop and stage of growth, lighting hours vary from 8 to 18 hours per day. • Recently CEA are converting to LED since the LED technology has improved in efficiency and the light spectrum required for cannabis growth.
CO2 generation	• Growers increase the CO2 concentration in their rooms to improve their yields. Most indoor growers maintain a range of 800 to 2,000 PPM, depending on the plants' growth stage. Levels above 2,000 PPM can damage plants, and anything above 3,000 PPM is dangerous to humans[12]. • CO2 is commonly added through compressed gas tanks since they are readily available, easy to set up, and do not add any extra heat to the grow room unlike CO2 generators do[12].



Source: www.AdaptiveAgroTech.com.

FIGURE 6. GENERAL EQUIPMENT IN A CEA

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[12] https://weedmaps.com/learn/the-plant/growing-cannabis-indoors-intro/

MARKET CHARACTERIZATION STUDY OBJECTIVES

The scope of this market characterization study involved the following objectives:

- Performing a literature review to research market forces, economic drivers, and regulatory factors.
- Conducting interviews with industry stakeholders: cultivators, growers, IOUs, vendors, and associations
- Analyze industry norms, energy savings potentials, greenhouse gas reduction (GHG), and energy reduction potentials.
- Provide recommendations of proposed incentive design.
- Outline proposed next steps for increasing ICA participation in IOU Incentive Programs
- Identify barriers, solutions, and provide recommendations to improve the participating of ICA customers in SCE territory.

TECHNOLOGY/PRODUCT EVALUATION

INDOOR AGRICULTURE LIGHTING TECHNOLOGY

The primary energy input for most CEA production facilities is lighting. Lighting power densities in the order of 10-35 W/ft^2 for CEA facilities [13], which typically accounts for between 30% to 50% of energy usage in CEA facilities[14]. When discussing and comparing lighting fixtures for indoor agriculture facilities, it requires an understanding of lighting technology concepts specific to horticultural lighting.

LIGHTING DEFINITIONS AND METRICS

A foundational metric for indoor lighting system design and operation is daily light integral (DLI), which is a measure of the amount of photosynthetically active radiation (PAR) received by the crop per day, measured in moles/m^2/day. PAR light is usually defined as light with a wavelength of approximately 400nm to 700nm and is fundamental to measuring the output and efficacy of horticultural light fixtures. PAR output of horticultural lights is reported in terms of photosynthetic photon flux (PPF), which is measured in micromoles of light output per second (µmol/s).

To achieve optimal illumination for plant health, horticultural light intensity is also measured at the canopy level in terms of photosynthetic photon flux density (PPFD), which is a measure of instantaneous PAR on a square meter basis, generally reported as µmol/s/m^2. Finally, horticultural lighting efficiency is measured in terms of photosynthetic photon efficacy (PPE or PE), which is a measure of PAR output per Joule of input energy, reported as µmol/J.

Lighting Power Densities (LPD) vary depending on crop light requirement, layout, and lighting technology, and can be higher in vertical depending on the number of stacked levels of plant production. Note that vertical farms almost exclusively use LED lighting, and typically have a LPD of 15W/ft^2 per vertical level of plant growth plane.

HIGH INTENSITY DISCHARGE

For non-vertical farming, HID fixtures are the industry standard with HPS, or MH fixtures being chosen depending on the light spectra required by the plants. MH fixtures produce more blue light while HPS fixtures produce more red and yellow light. High-wattage HID fixtures are common with 600-1000W fixtures seeing frequent use. These high-wattage fixtures produce large quantities of waste heat which increase the cooling load.

Double-ended HID fixtures have been gaining popularity since they have higher efficacy than single-ended fixtures but are generally still considered a “known quantity” by growers. Double-ended HID fixtures generally have similar high wattages as single-ended fixtures (600-1000W).

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[13] https://www.energy.gov/sites/prod/files/2020/07/f76/ssl-agriculture-jun2020.pdf

[14] https://www.burnsmcd.com/insightsnews/tech/energy-challenges-of-indoor-agriculture

LINEAR FLUORESCENT

Linear fluorescent fixtures are becoming less common for CEA facilities for all stages of growth. Depending on the age or infrastructure of the facility, either T12, T8, or T5 lamps are used. Fluorescents are more common for smaller CEA facilities and are less practical and cost-effective more medium or larger buildings. However, fixtures are typically lower wattage than available HID fixtures, and therefore produce less heat. This reduces HVAC load, and allows for lamps to be placed closer to plants, allowing for vertical stacking.

LED LIGHTING

LIGHTING EFFICACY AND COST

LED lighting technologies have been increasing in global popularity for all forms of CEA facilities with estimates to be the global standard by the next decade[15]. The adoption of LEDs for CEA facilities within the USA have also been following this trend with LED market share estimates varying between 25% to 40% depending on the study.

One reason LED fixtures have been slow to gain traction in recent years, is primarily due to the high up-front cost of LEDs. An LED fixture producing similar light output to a 1000W HPS fixture can cost 3-4 times as much as the HPS fixture. Modern horticultural LED fixtures have efficacies in the range of two times that of single-ended HPS fixtures. This means reduced electricity consumption, and reduced load on the HVAC system.

HEAT OUTPUT AND HEAT LOAD

Additionally, the reduced heat output allows fixtures to be placed closer to the plants, allowing for vertical stacking, similar to T5HO fixtures. Due to the reduced heat output, LED fixtures have nearly 100% market share in vertically stacked applications. Water-cooled LED fixtures have also been developed, which reject heat to a fluid loop to be moved outside the growing space, further reducing HVAC load.

ADOPTION MARKET BARRIERS

In addition to higher cost, LED fixtures have a minor a negative perception within the industry which has resulted in multiple university and research studies[16,17,18]. These research studies, conducted by LED manufacturers, have led to multiple advancements in LED technology and controls to improve the quality of the plants' health.

However, several early experiments with LED fixtures in indoor agriculture were conducted when LED technology could not produce optimal lighting spectra for agriculture. Current LED horticultural fixtures are capable of generating a variety of different light spectra depending on needs, and some LED fixtures can deliver multiple light spectra with a single fixture. Typical grow lights used in CEA are summarized in the **Table 2**[19].

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[15] https://www.psmarketresearch.com/market-analysis/grow-lights-market

[16] http://ijabe.org/index.php/ijabe/article/view/4847

[17] https://www.ajol.info/index.php/ajb/article/view/132744

[18] https://www.abepublishing.org/journals/index.php/ijabe/article/view/5178

[19] https://www.energy.gov/sites/prod/files/2017/12/f46/ssl_horticulture_dec2017.pdf

TABLE 2. SUMMARY OF LIGHTING TECHNOLOGIES USED FOR INDOOR AGRICULTURE

LIGHT TYPE	DETAILS	FIXTURE PPE (µMOL/J)	COST PER WATT ($/W)
T5HO fluorescents	1. Can be placed close to the plant and stacked vertically, 2. Limited heat and light intensity reduce the chance of damaging the seedlings. 3. 4 ft, 220W fixture, approx. $100-200 4. Run time – 24 hours per day	0.8-1.0	$0.38/W
Ceramic Metal Halide (CMH)	1. Spectra contains bluer light. 2. Lighting is typically used for 18 to 24 hours per day. 3. Fixture cost is Approx. $200	1.0-1.5	$0.24/W
Single ended (SE) high pressure sodium (HPS)	1. Spectra contain more yellow/red. 2. Preferred for flowering, but also used for full growing cycles with a single fixture	1.3-1.7	$0.23/W
Double-ended (DE) HPS	1. Significantly more output light than single-ended 2. Fixture cost is Approx. $400-500 3. Run time – 12 hours per day	1.7-2.0	$0.28/W
LED[20]	1. Marketed as 40% reduction in power and energy use over traditional HID fixtures. 2. Capable of being dimmable. 3. Variable color spectrum available 4. Less heat emission 5. 600W Fixture is approx. $1,500	2.0-4.0	$1.50 - $2.60/W

HVACD TECHNOLOGY

Creating a suitable environment for growing plants indoors requires specialized heating, ventilation, air conditioning, and dehumidification (HVACD) systems that meet different requirements than those required for a typical residential or commercial location. In particular, growing plants adds a considerable lighting heat load. Growing plants also add a large latent load to a space through 1) the evaporation of water from surfaces, and 2) the transpiration of water vapor via leaf stomata through photosynthesis.

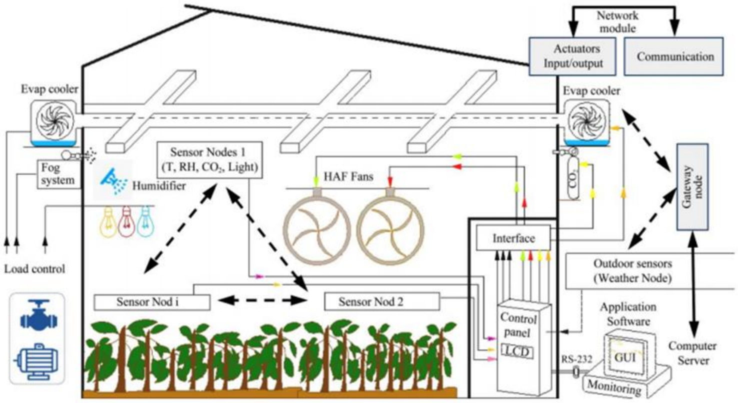
G. Schimelpfenig, "LED lighting For Cannabis Cultivation & Controlled Environment Agriculture," Resource Innovation Institute, December 2019. [Online].

[20] G. Schimelpfenig, "LED lighting For Cannabis Cultivation & Controlled Environment Agriculture," Resource Innovation Institute, December 2019. [Online].

VAPOR PRESSURE DEFICIT OR DIFFERENTIAL

A critical and often overlooked concept in the selection, design, and operation of CEA HVACD equipment is *vapor pressure deficit/differential* (VPD). VPD is the difference between the amount of water contained in the CEA facility's air versus the maximum amount of water the air can contain at a given temperature and is typically measured in kilopascals (kPa).

Operating a CEA HVAC system to achieve an optimal VPD enables efficient evapotranspiration, which translates to efficient uptake of water and nutrients. Achieving optimal VPD minimizes plant stress and disease susceptibility, as well as maximizing plant growth rate. VPD is modulated through temperature and humidity manipulation, and target VPD levels vary depending on the crop type, growth phase, and lighting intensity. For example, Figure 7 provides VPD targets for tomato plants that growers need to achieve to ensure the optimal environment for the plants' growth.



Source: www.AdaptiveAgroTech.com.

FIGURE 7. VAPOR PRESSURE DEFICIT CHART FOR TOMATOES[21]

Each climate control component system (heating, ventilation, cooling, and dehumidification) is interrelated, and the design and operating conditions vary based on the scale, location, and type of crop(s) being grown. For this reason, there is no "one-size-fits-all" technology, and the most efficient solution for new construction, retrofit, and/or retro commissioning is highly case-dependent. The following sections provide a high-level overview of HVACD considerations and technologies for CEA operations.

COOLING

CEA facilities typically have substantial heat loads produced by intensive lighting systems. In order to maintain the optimal VPD for plant growth, mechanical cooling systems are often (though not always) necessary. The most common cooling systems in CEA facilities include direct expansion (DX) units and chilled water systems. Common DX cooling systems include split, mini-split, and roof-top units (RTUs), which are the most widely used and commercially available.

DX cooling systems are the most common cooling solution found in CEA facilities, and have several disadvantages. Most DX solutions are not designed for intensive year-round use, which can result in early failure and higher operation and maintenance during their useful

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[21] http://www.tucson-bca.com/vpd/tomatoes.html

life. Additionally, DX systems typically no not have the ability to control humidity, resulting in the need for stand-alone dehumidifiers.

Chilled water systems achieve higher efficiencies than refrigerant-based DX systems, and have several distinct advantages including longevity. Chilled water systems utilize air handling systems which operate independently of compressors, which allows the CEA facility to operate multiple rooms without comingling air. Chilled water systems are more expensive and complex than DX systems, but offer greater air handling capabilities and reduced operating costs. It is more common to see chilled water-based HVAC systems in large commercial or warehouse buildings.

HEATING

Heating systems are not always found in CEA facilities due to the considerable heat created by the lighting system and other equipment. However, larger facilities often use hot water boiler systems to distribute heat via hydronic distribution systems. CEA facilities using boilers can improve their efficiency through standard boiler efficiency measures, such as through the use of condensing boilers and advanced boiler controls. For CEA facilities that do require heating, furnaces and heating hot water are very common with small (<2.5%) using other heating tech such as heat recovery for dehumidification.

MECHANICAL VENTILATION

Mechanical ventilation (other than that which is used for cooling) typically represents a minor energy load in CEA facilities, ranging from 2% to 10%. The primary function of ventilation is to mitigate stagnant air pockets and create a more homogenous climate through air circulation. Depending on the facility and plants being grown, ventilation provided from the HVAC system may be sufficient to keep the growing area at its optimal climate.

For CEA facilities with additional mechanical ventilation, it is common for circulation fans to be mounted horizontally, typically with a blade diameter ranging from 12” to 20”. Although uncommon, CEA facilities may make use of exhaust and/or intake fans to replenish air within the facility. Another less common ventilation technology is high volume low speed (HVLS) fans, which is also used for thermal destratification.

DEHUMIDIFICATION

Maintaining proper humidity levels is important to avoid plant diseases and mold problems. While dehumidification can be handled entirely or in part by the cooling system (e.g., split, or packaged DX systems or chilled water systems), there is often a need for additional dehumidification capacity in CEA facilities. To remove the desired amount of moisture, stand-alone dehumidification units are commonly used. These systems typically consist of unitary compressor-based or desiccant-based humidifiers.

Dehumidification systems (excluding desiccant-based systems) are capable of capturing and recycling condensate water collected through the dehumidification process, which can then be filtered/treated (as necessary) and reused for irrigation. This feature may become increasingly important in locations where water scarcity and water use restrictions are occurring. Recycling water through dehumidification systems may also enable CEA facilities to take advantage of rebates through utility or government sponsored water conservation programs.

ADVANCED CONTROLS

Advanced climate control systems that integrate and coordinate the components of CEA HVAC systems are becoming increasingly common and sophisticated. This technology enables growers to remotely monitor and automate HVACD systems via cloud-based interfaces. These systems typically rely on internet-of-things (IoT) sensors to feed real-time data to the control software, which can then be used for remote monitoring and/or remote control of HVACD equipment. This technology is in early stages of commercialization for CEA facilities. But the technology is likely to rapidly gain in popularity due to the advantages it offers in terms of EE and demand management.

CODES, STANDARDS, AND POLICY

2022 CALIFORNIA TITLE 24 CODES AND STANDARDS EFFICIENCY PROPOSAL

Despite the proliferation of CEA in the last two decades, no policies in California directly address the issue of EE or GHG cost/effects. Even Title 24, California's Building Energy Efficiency Standards, does not address non-residential controlled environment horticulture until the 2022 code cycle. The future code proposes the following code changes[22].

1. Horticultural lighting minimum efficacy
    a. Mandatory requirement for minimum PPE of up to 2.1 micromoles per joule (μMol/J) for luminaires used for plant growth and maintenance in indoor growing facilities with more than 40 kW the upfront cost of this transformation could be as much as $62,000 for each 1,000 square feet of growing canopy[23].
2. Efficient dehumidification and reuse of transpired water
    a. Integrated HVAC system with on-site heat recovery for reheating dehumidified air; or
    b. Chilled water system with on-site heat recovery for reheating dehumidified air; or
    c. Solid or liquid desiccant dehumidification system
3. Greenhouse envelope standards.

However, there are no intermediary standards currently in place. Any EE requirements are left to the counties to manage and require.

POLICIES AND PROVISIONS ON URBAN AGRICULTURE

There are policies available for urban agriculture but not specifically for Indoor farming. Urban Agriculture (UA) is the practice of cultivating, processing, and distributing food in or

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[22] "Codes and Standards Enhancement (CASE) Initiative2022 California Energy Code, Controlled Environment Horticulture," Energy Solutions and Cultivate Energy and Optimization, June 2020. [Online]. Available: https://title24stakeholders.com/wp-content/uploads/2020/06/NR-CEH-Draft-CASE-Report.pdf.

B. Gunn, "California cannabis energy mandates add undue cost burden to growers," Marijuana Business Daily, 22 July 2020. [Online]. Available: https://mjbizdaily.com/california-cannabis-energy-mandates-add-undue-cost-burden-to-growers/.

[23] B. Gunn, "California cannabis energy mandates add undue cost burden to growers," Marijuana Business Daily, 22 July 2020. [Online]. Available: https://mjbizdaily.com/california-cannabis-energy-mandates-add-undue-cost-burden-to-growers/.

around urban areas. Thus, CEA is a form of Urban Agriculture, but UA covers all kinds of farming methods both indoors and outdoors. Since virtually every American municipality uses the International Building Code ("IBC") as a building model code, any weaknesses or ambiguities in the IBC is inherently shared with municipalities that follow it. Currently, the IBC does not have provisions addressing buildings intended for large-scale indoor crop production[24].

LOCAL ORDINANCES AND BUILDING CODES FOR URBAN AGRICULTURE

Generally, zoning ordinances and building codes regulate the use and structure of a building. When these ordinances and codes are deficient on defining CEA within UA, ambiguities, regulation gaps, and lack of incentives occur. For example, occupancy groups define the type of building depending on its intended use (Assembly, Business, Educational, Factory, High-Hazard, Mercantile, Residential, Storage, etc.). When the occupancy group is defined and addressed, then the regulations, taxes, and incentives are clearer for the governing locality, utilities, and the consumer. Additional concern such as energy use, electrical, fire, life safety, water quality, and air quality can also be addressed[25].

With respect to vertical farming, knowing which occupancy group(s) a vertical farming structure fits into is important because it determines maximum height, number of stories, what zone a vertical farm can operate in, to what extent the farming process is allowed on site and what is necessary to convert a building for one use to CEA[25].

Currently, IBC provides that when a building changes occupancy groups, it must meet the requirements of additional codes, such as the International Energy Conservation Code ("IECC"), at least in municipalities where this is adopted. Application of the IECC depends on the occupancy group classification for a particular structure. If CEA is undefined, the regulatory gaps persist. As of 2018 IECC, lighting used in indoor horticulture is not regulated for efficiency requirements[25].

CALIFORNIA'S URBAN AGRICULTURE INCENTIVE ZONES ACT

California's Urban Agriculture Incentive Zones Act ("UAIZ Act") allows acreage from one-tenth of an acre to a maximum of three acres. But UAIZ applies to "vacant, unimproved, or blighted lands [that can be] converted for small-scale agricultural use." However, this requirement provides no guidance for larger, commercial CEA. Since it provides no specific benefit for CEA, capital funding is hard to obtain. California will need to look outside of its borders for EE policies implemented in other states[25].

2018 U.S. FARM BILL

Federally under the 2018 US Farm Bill[26]:

(§7212). Urban, Indoor, and Other Emerging Agricultural Production Research, Education, and Extension Initiative.

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[24] C. Simpson, "Updating the Building Code to Include Indoor Farming Operations, Vol. 15 No. 2, Art. 5," Journal of Food Law & Policy, 2019. [Online]. Available: https://scholarworks.uark.edu/jflp/vol15/iss2/5/.

[25] C. Simpson, "Updating the Building Code to Include Indoor Farming Operations, Vol. 15 No. 2, Art. 5," Journal of Food Law & Policy, 2019. [Online]. Available: https://scholarworks.uark.edu/jflp/vol15/iss2/5/

[26] "2018 Farm Bill Primer: Support for Urban Agriculture," Congressional Research Service, 16 May 2019. [Online]. Available: https://fas.org/sgp/crs/misc/IF11210.pdf.

- Authorizes competitive grants to facilitate urban agricultural production, harvesting, transportation, and marketing, among other activities. It provides $10 million in mandatory funding (FY2019) and authorizes $10 million in annual appropriations through FY2023. It also directs the USDA to study urban agriculture as part of the 2017 Census of Agriculture.

(§2307). Conservation Innovation Grants and Payments (§2307).

- It expands the existing competitive grants to cover partnering with farmers to develop innovative practices for "urban, indoor, or other emerging agricultural operations," including initiatives for "testing new or innovative conservation approaches." Provides $25 million annually through FY2023 from mandatory funds for the Environmental Quality Incentives Program.

Federally, there is potential funding to study and develop policies but provides no other guidance specifically for CEA as it does for UA.

MARKET CHARACTERIZATION APPROACH

INTERVIEWS

QUESTIONNAIRE DEVELOPMENT

The recent growth of indoor agriculture for food production has stimulated interest from utilities in understanding the current status of the CEA market. Of particular concern is the future growth in energy usage for this market. The survey and interviews conducted as part of this study are intended to gain insight from various stakeholders across the indoor agriculture market.

The expected outcome is a representative overview of the market. The study seeks to obtain a holistic picture of the indoor agriculture industry as it relates to energy usage and to assess the market for full greenhouse gas reduction potentials. From the survey we hope to find a matrix of what the energy challenges are and opportunities to be found.

To get a representative sampling of industry stakeholders, short survey questions were developed and targeted towards Indoor Agriculture growers, equipment vendors, designers or engineers, Associations and Policy Makers (the "stakeholders"). The questions for the stakeholders included both closed and open-ended questions. The open-ended questions were intended to create a deeper conversation and to adapt the questions based on the stakeholders' responses or feedbacks. Hard data collection was not the primary goal in the questionnaire. But the questions were intended to get an overview of the industry itself. The targeted questions were intended to develop industry insight and identify barriers in market adoption of EE techniques in the grow facility.

STAKEHOLDER OUTREACH

TELEPHONE SURVEYS

Outreach to stakeholders was performed by email and telephone calls. A quick explanation for the survey intent and requests for scheduling a time to complete the survey were scheduled and completed with qualified participants. The surveys were later compiled to determine any commonalities to reinforce the research data already compiled, and any new or expansive information.

STAKEHOLDER POOL

Outreach to various stakeholders resulted in responses and subsequent interviews with

- 3 indoor growers,
- 3 industry associations,
- 3 HVAC vendors,
- 4 lighting vendors, and
- 3 controls vendors/designers.

Interviews with vendors included conversations with both sales staff, and design/engineering staff.

INDOOR AGRICULTURE GROWERS

The surveyed stakeholders each have an interest in the success of the Indoor Agriculture industry. Indoor Agriculture growers obviously are interested in the success of their business for economic reasons. Having open conversations with growers gives us insight on their technical/energy challenges, knowledge, and their current equipment infrastructure. Hearing their reasons for making equipment choices and doubts regarding technical advances gives us more depth on possible solutions that may be implemented.

INDOOR AGRICULTURE VENDORS

Indoor Agriculture equipment vendors were surveyed to determine the driving forces in which growers selected equipment. Although growers may desire to buy certain technology to run their facility, where their actual dollars go are shown by the actual sales made from the manufacturers and equipment sellers. Additionally, the vendors can confirm if sales were made directly to growers or to third party consultants or designers/engineers.

DESIGNERS AND ENGINEERS

The discussions with designers/engineers reinforced the frame of mind the growers operate their business and the actual technologies and equipment used in the buildings. They bridge the gap between the business minded growers and tech skills to get the grower’s vision implemented.

INDOOR AGRICULTURE ASSOCIATION

The role of associations is primarily as advocates for the growers. They provide a sounding board and community connections for growers to express their trials, tribulations, and successes in the indoor agriculture community with like-minded persons. They were open to discuss most topics especially with the intent to improve the growers’ community (re. cost, energy, licensing, production, etc.) and were an open source of information although weak with hard data.

MARKET CHARACTERIZATION RESULTS

INTERVIEW FINDINGS

LIGHTING

All the surveyed stakeholders cited LED lighting as becoming the most commonly used technology for indoor agriculture. All growers who responded to the interview and survey used LED fixtures in their facilities. Lighting vendors who serve the California market, 50% of which sell exclusively in LEDs, summarized that a large majority of new sales have been LEDs with a smaller quantity of T5 fluorescent and HID lighting sold.

Likewise, surveyed industry associations noted that LED lighting is generally the “go-to” for food production, with other technologies such as HPS generally being reserved for cut flower or cannabis production. All surveyed parties noted that the higher efficiency and reduced heat output of LED fixtures was the primary driver behind wide proliferation of LEDs. The reduced heat output is especially important in vertical farming since the stacked racks of plants and lighting necessitate close placement of plants to lighting fixtures.

The flexibility of LED fixtures was cited by vendors as another major factor for their popularity in the indoor agriculture space. Different crops will often require different LPDs, and/or lighting spectra. While traditional lighting technologies would require different lamps or even entirely different fixtures to be installed to meet these requirements, LED fixtures are available which can be tuned to meet different power density or spectra requirements. This makes LEDs extremely attractive to growers who want to grow multiple types of crop in the same facility.

HVAC

Based on survey results, heating and cooling requirements are met with a variety of technologies, including split-systems, packaged units, and hydronic boiler/chiller systems. According to one vendor, the technology used depends largely on the size of the customer, with large growers generally using a hydronic system for heating and cooling, and smaller growers generally using split systems or DX packaged units.

Information gathered from surveyed growers, associations, and other vendors, tended to align with this. One other vendor cited seeing exclusively hydronic cooling systems, though they also worked exclusively with larger customers (>50,000 ft^2). All surveyed growers had a growing area of less than 10,000 ft^2, and 2/3 used packaged DX/heat pump units for both cooling and heating. However, 2/3 of the interviewed growers used hydronic cooling despite their small size. One grower used a combination of hydronic cooling and DX packages while one used exclusively hydronic cooling. No surveyed growers used hydronic heating.

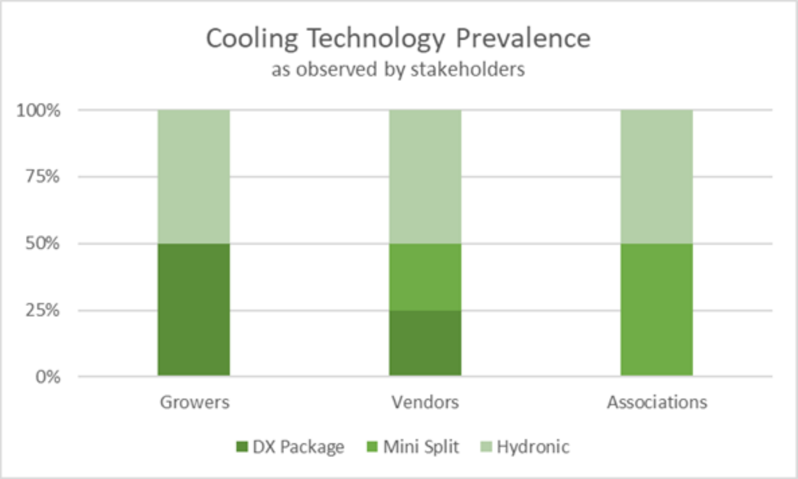

FIGURE 8. COOLING TECHNOLOGY PREVALENCE

DECISION DRIVERS AND BARRIERS

GROWERS' CONCERNS

Growers cited concerns around pests and pesticides, as well as overall product quality as their primary reasons for growing indoors. Secondary concerns (according to all stakeholders) included proximity to markets, space and water efficiency, crop resiliency, and general environmental control. The move towards CEA in California is a unique as there is an existing infrastructure for traditional outdoor farming. The growth of the CEA market is driven by a combination of technology, water, product quality, and ability to control climate.

IMPROVEMENT OF ENVIRONMENTAL CONDITIONS USING ENERGY MANAGEMENT SYSTEMS

To improve the control of the environmental conditions in the growing area, some technology focused growers have adopted environment management systems (EMS). Temperature, humidity, lighting density and CO2 levels can all be monitored and adjusted using the EMS, hence have gained traction to improve crop yield and in some cases EE. Larger growers tend to have more intricate environmental control and are able to afford such systems, therefore are more common among them.

Based on various interviews, EMS integration is largely tied to the size of the facility, where growers under 10,000 ft^2 are only 20% likely to use an EMS of some sort, about 30-40% of growers between 10,000 and 50,000 ft^2 have an EMS, and growers larger than 50,000 ft^2 in canopy area are likely to have an EMS in 60% of cases. One of the largest perks to having a comprehensive EMS system onsite is the ability to track energy consumption by area, equipment, or process. With this, growers can understand which equipment is operating inefficiently and may require retrofitting.

GROWERS' PREFERRED HVAC OPTIONS

HVAC systems adopted by indoor growers consist primarily of packaged and split units, mainly due to their lower initial costs. These units can be purchased off the shelf with easy installation. Larger growers may lean towards a hydronic (chilled water-based) HVAC system throughout the facility or use existing equipment if the infrastructure was preexisting. Standalone dehumidifiers are commonly used to counter the effects of evapotranspiration, removing moisture from the air that the crops produce during growth.

CO2 MONITORING

CO_2 monitoring is also abundant to help ensure optimum environmental conditions. However, most monitoring is performed manually with adjustments made by either purchasing CO_2 or producing the gas through combustions. Very little consideration is taken towards EE when it comes to environmental control, mainly due to the initial costs and lack of awareness by growers.

LACK OF HVAC BEST PRACTICES

Associations and HVAC vendors noted that there is currently a lack of established best practices with regards to HVAC for indoor agriculture. Based on vendor responses, growers tend to choose the lowest-cost system that can meet the temperature and humidity requirements of their crop or crops. While some larger indoor growers have the background knowledge to consider efficiency and ongoing operating cost, smaller growers are primarily concerned with up-front cost.

Design engineers have the knowledge to spec out a system based on provided design points, but generally do not have the background knowledge in agriculture to determine whether the points they are given are realistic or necessary, especially when dealing with growers wanting to grow a variety of crops. Establishment of HVACD and controls best practices for indoor agriculture would be helpful for both growers and vendors in requesting and developing more efficient agricultural HVAC systems.

LACK OF ADEQUATE CUSTOMIZED INCENTIVES

Several surveyed stakeholders noted that while financial EE incentives are an important driver of technology adoption, existing incentive structures can have unintended consequences, tending to look at the incentivized system in a vacuum. For CEA facilities, the existing incentives in California do not provide sufficient capital offset to meet a reasonable return on investment for most growers.

One of the largest barriers facing growers is the thin margins associated with growing vegetables. Current incentive programs tend to focus on like-for-like equipment replacement, and as a result, growers will look at equipment that provides the maximum possible incentive, rather than equipment that best meets the needs of the facility. One association provided examples of incentives actually increasing the total energy used by a facility since LED lighting resulted in an increased load on the facility's heating system.

IOU STAKEHOLDER FEEDBACK AND ASSOCIATED IMPACTS

For this study, 12 utility representatives from SCE, PG&E, SMUD and others around the U.S. were interviewed and their experiences are shared in this section. A large majority of the interviewed representatives have developed programs for CEA customers with the primary focus on cannabis growers.

However, most interviewees have either worked with or their programs serve all types of CEA facilities. Identified barriers did vary among IOUs and geographic locations but there were commonalities and unique issues that are specific to Southern California.

LIMITED ENERGY SAVINGS FOR IOU PORTFOLIO AND LIMITED CUSTOMER INTEREST

Providing incentives for the technologies common to CEA facilities are not new to a majority of IOUs. Lighting, HVAC, pumping, and other smaller prescriptive incentives are provided to a variety of sectors and end use customers. But not all IOU programs target or serve CEA facilities. From the perspective of the IOUs, based on interviews for this study, CEA facilities are either a minor portion of their portfolio or are already served by existing offerings. The resource cost to develop customized approaches, programs, or incentives are not viewed as cost effective for the CEA sector. Other barriers observed are the limited interest by IOU customers as they operate under very thin margins and therefore capital investment is limited.

LACK OF SUFFICIENT CUSTOMER INCENTIVES EQUATES TO LESS PROGRAM PARTICIPATION

A portion of IOUs have varied their incentive programs or structures to overcome this barrier. However, this also resulted in different programmatic issues. These barriers typically stem from developing a cost-effective program for CEA customers while providing sufficient incentives for program participation.

For CEA facilities, the available capital barrier is still the main driver for reduced interest to investing in EE technologies, which translates to less program participation. The alternative programs that offer variable incentives or design support have not viewed a significant improvement in participation over the more traditional custom incentive programs.

HEAVY REGULATORY COMPLIANCE REQUIREMENTS AND BURDENSOME INFLUENCE DOCUMENTATION

Within California, IOUs also have to struggle with influence documentation set by the CPUC for customers’ program participation. For newer CEA facilities, capital investment is typically secure, and these sites are technology-focused with vertical growing, automation, and advanced sensor integration. This minimizes program participation as the customers are already exceeding standard practice on their own; thus, often ineligible for the existing customer incentive programs. For existing CEA facilities that participate in incentive programs, influence is typically monetary as margins for CEA facilities can be very thin and capital investments are very risky.

EXPENSIVE TO ADOPT EE EQUIPMENT

Although EE equipment is encouraged by utilities, it remains the expensive alternative and often vary in their return on investment between 2 to 5 years, or greater. Although year-round harvest is one of biggest advantages of indoor farming, their product demand is not always consistent. This results in short fluctuations in available capital when growers have the ability to implement EE technologies.

SHORT PAYBACK PERIODS REQUIRED

Indoor growers usually cannot handle long term losses let alone afford expensive EE technologies. The custom incentive process often results in a long timeline before approval (4 to 8 weeks), which deters customers from participating. Many indoor agricultural facilities are relatively new and indoor cannabis growers have only recently legalized.

Thus, they were not able to take advantage of EE incentives the way other industries have and will continue to lag behind until clear energy standards are established and/or impactful incentives are readily available.

LACK OF SUFFICIENT EDUCATION AND OUTREACH

California utilities, vendors, and growers are working on overcoming the barriers to achieve widespread EE adoption in indoor growing. But it all starts with spreading knowledge and awareness according to multiple experts who were interviewed.

Indoor agriculture is a ‘word of mouth’ community amongst growers, so it is important to educate and provide relevant customer examples and case studies. It is also important that growers understand the benefits of energy savings, and how they can be achieved without compromising the quality of their product. Some of the representatives discussed crop testing with EE alternatives such as LED lights in comparison to typical HPS or MH fixtures to demonstrate that they do not have adverse effects on yield or crop quality.

There are a significant number of growers who are aware of such technologies yet find them unattainable either due to their initial cost or because of the long process associated with the application for financial incentives. An idea from a few of the interviewees was to develop a sub-sector for indoor growing with incentives tailored to their upgrades. This would help address eligibility issues and perhaps accelerate the incentive application process which the utility representatives highlighted as key for indoor growers’ confidence in the system. The overall message was to increase awareness, demonstrate proof of product quality and energy savings, and provide uncomplicated incentives that will help improve the payback period of EE technologies.

MARKET ANALYSIS DISCUSSION

POTENTIAL MARKET SAVINGS

Within California, there is a documented growth of indoor agriculture over the past few years which is primarily attributed to Cannabis. Specifically, growth in the CEA sector has been attributed to advanced vertical farms using the newest lighting, automation, and controls with other newer EE growing strategies. While traditional indoor farms are being built, they are fewer in quantity and are typically built for geographic or social needs.

For this study, the potential is limited to the impacts on the Southern California market. The following sections will review the market savings potential for several technologies and their potential to reduce load from the grid.

LIGHTING

Within CEA facilities, LEDs are approaching standard practice for new construction buildings. However, there is still a large portion of the CEA market that utilized other technologies such as HPS, MH, and fluorescent fixtures. Based on SCE study of indoor horticulture customers, over 50% of growers use multiple lighting technologies such as LEDs with Fluorescents, LEDs with HIDs, and a smaller percentage (18%) that use only LEDs[27].

Based on the interviewed growers, there are very thin margins in CEA facilities which results in the mixed technologies and lower number of LED only buildings. When determining potential savings across the CEA market, the challenge in comparing different types of fixtures is using an appropriate metric to avoid comparing apples to oranges.

The metric used to determine level of service for horticultural lighting is Photosynthetic Photon Flux (PPF), which is a measure of the number of photons produced by a fixture that are usable for photosynthesis. Photosynthetic Photon Efficacy (PPE) is a related measure of how efficiently a given fixture can produce PPF. While there are other measures of lighting performance, such as color rendering index (CRI), a measure of how accurately colors appear under a fixture and lumen output (a measure of the visible brightness of a fixture), these metrics are not generally applicable to various types of horticulture. **Table 3** summarizes the PPE ranges of various lighting technologies.

TABLE 3. PPE RANGES OF VARIOUS LIGHTING TECHNOLOGIES

LIGHTING TECHNOLOGY[11]	PPE RANGE (µMOL/J)	COST/WATT
Metal Halide HID	1.0-1.5	$0.24/W
T8 Fluorescent	0.7-0.84	$0.40/W
Single Ended High-Pressure Sodium HID	1.3-1.7	$0.23/W
Double Ended High Pressure Sodium HID	1.7-2.1	$0.28/W
LED	2.0-3.0	$1.50/W

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[27] Indoor Horticulture Lighting Industry Stand Practice Review – Final Report. Evergreen Economics. August 22nd, 2019.

CALIFORNIA TITLE 24 PROPOSED CODES AND STANDARDS EFFICIENCY IMPACTS TO NEW CONSTRUCTION

With the upcoming changes to Title 24 in California for Controlled Environment Horticulture, the efficiency required for new construction buildings will naturally reduce load on the grid. The most recent CASE study is proposing a PPE of 2.1 µMol/J as the code minimum for loads exceeding 40 kW for indoor. This proposed PPE is reflective of 92% of Design Light Consortium (DLC) approved fixtures having a PPE of 2.1 or greater[28]. Other agencies such as IECC are proposing a PPE of 1.6 µMol/J as a recommended standard with the current average PPE on the DLC is 2.48[29].

While these proposed efficacies will affect new construction or code triggering modifications, they do not have impacts on existing facilities using lower efficient technologies. Based on stakeholder interviews, the barriers to implementing LEDs include availability of upfront capital, education on LED light impacts on quality, and reluctance to change from the historical norms. Through natural attrition, a very large portion of existing facilities will eventually transition to LED fixtures with a minority staying with HID or other technologies.

SPACE COOLING

Space cooling needs are met by a variety of technologies. Generally, HVAC systems are sized by either BTU/hr. output, or tons (1 ton = 12,000 BTU/hr.), and efficiency is expressed as the Energy Efficiency Ratio (EER). For small and medium facilities, direct expansion packaged units are the most common. These are available a wide variety of sizes (generally 1-10 tons for small facilities) and efficiencies (9.7-11.2 EER) with newer high efficiency options exceeding an EER of 12. Split-system heat pumps are another available technology which have very similar efficiencies to DX package units with improved efficiency when in heating mode. Within Southern California, there is limited number of heating days in comparison to the cooling load required and therefore little efficiency gain between heat pumps and DX units.

As facilities increase in size, packaged units are still often used which are available in sizes upwards of 100 tons. Hydronic chiller systems see occasional use in larger facilities which have the ability to greatly exceed package unit efficiencies with equivalent EER range from 12 to 15. Chiller based cooling systems are more expensive than package units and require water piping loops, pumps, and potentially cooling towers to support them. Other benefits of chiller-based systems include the ability to have tighter temperature control, improved humidity control, and the ability to use water cooled LEDs.

Horticulture-specific packaged units are available but are relatively recent and do not have much market penetration. These units generally have a comparable EER to standard packaged units, but have the benefit of including a dedicated dehumidifier, and generally are packaged with a horticulture-focused control system.

MECHANICAL VENTILATION

Ventilation fans are frequently used within growing spaces to maintain consistent temperature and humidity conditions throughout the space. These fans vary in sizes ranging from ¼ HP to 5 HP based on their configuration and quantity. While EE options are available for fan motors of this size, due to the small motor size and relatively small gains in efficiency between standard and high efficiency models, the magnitude of available savings is limited. There are potential savings for upgrading horizonal fans to higher efficiency

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[28] https://title24stakeholders.com/wp-content/uploads/2020/10/2022-T24-NR-CEH-Final-CASE-Report.pdf

[29] The average PPE of 2.48 is based on 208 fixtures that are approved as of 12/1/2020 on the DLC. https://www.designlights.org/

models that will improve air circulation and temperature regulation but should be assessed individually.

DEHUMIDIFICATION

As a result of indoor growing, the air within the growing area needs to be dehumidified to meet the desired levels in the air. The most common types of dehumidifiers are portable dehumidifiers you can purchase online or from a local retailer. The dehumidifiers come in various designs, sizes, and capacities which is specified as pints of water removed per day (or liters of water).

Energy Star has designated an energy performance standard for portable dehumidifiers which is designated by Liters per kWh based on three different capacity bins. During the interviews with growers, there was not a lot of information known on the make or model of dehumidifiers used in the growing area. Based on Energy Star, a standard dehumidifier uses 15% more energy than efficient unit[30].

SOUTHERN CALIFORNIA MARKET POTENTIAL

IA facilities have varying energy density per square foot ranging from 40 kWh to 150 kWh per square foot based the size, crop, and configuration of the building. Other factors that influence energy usage are lighting hours, temperature control, lighting technology, lighting density, and many other plant specific requirements. Unlike traditional outdoor farming, CEA facilities allow for year-round production with multiple harvests and can be located closer to the customers.

In additional to electrical energy, various fuels (such as Natural gas or Propane) in a commercial CEA facility are used for several purposes, such as a CO_2 source and as a substitute electrical source. The CO injected into CEA facilities can be produced industrially (from tanks) or by burning propane or natural gas within the grow room contributing about 1–2% to the carbon footprint and represents a yearly U.S. expenditure of $100 Million.

Off-grid diesel- and gasoline-fueled electric generators have per-kilowatt-hour emissions burdens that are 3-4 times those of average California electricity grids. Vehicle use associated with production and distribution contributes about 15% of total emissions and represents a yearly expenditure of $1 billion.

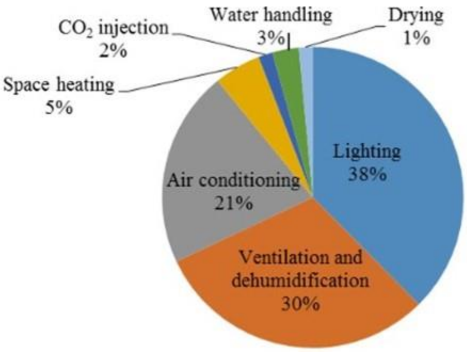

FIGURE 9. ENERGY USAGE FOR GROW ROOMS

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[30] https://www.energystar.gov/products/appliances/dehumidifiers

EE SAVINGS POTENTIAL ESTIMATES

There is a lack of detailed information on California's total energy usage for CEA production that is publicly available. However, there are multiple estimates and surveys that can be used to extrapolate the energy consumption of the CEA market which excludes cannabis. Using a survey of end-users in Southern California, a breakdown of crop types, existing blend of lighting technology, and approximate square footage of CEA facilities in Southern California, full implementation of EE technologies across all end uses would result in approximately 37.6 GWh reduction when compared to existing standard practices[31]. While this value is unlikely to be achieved in the near future, it does provide insight on the total savings that can be achieved.

2022 CALIFORNIA TITLE 24 CODES AND STANDARDS EFFICIENCY PROPOSAL

Conversely, the 2022 Title 24 CASE Report on Controlled Environment Horticulture proposed minimum efficiency requirements for both lighting and dehumidification. In particular, the CASE report proposed a minimum efficacy requirement of 2.1 μMol/J for indoor horticulture. This would reduce the total market savings potential significantly since LED lighting would be essentially required as baseline for new construction and major renovations.

100% EE TECHNOLOGIES IMPLEMENTATION EMISSION REDUCTIONS SAVINGS POTENTIAL

Based on the above electric savings potential, 100% implementation of EE technologies in the CEA facilities would result in a 6.77 MT of CO_2 reduction in GHG emissions when compared to baseline. It should be noted that the energy use intensity for indoor horticulture is significantly greater than traditional outdoor farming, resulting in increased GHG emissions. Some of this energy use may be offset by reduced GHG emissions produced by transportation, since CEA facilities can be located closer to retail locations than outdoor farms. Water pumping is also an end-use that has a lower energy requirement for indoor horticulture when compared to outdoor. However, these amounts are dwarfed by the additional energy required by lighting and HVAC for a fully enclosed CEA facility.

INDOOR AGRICULTURE MARKET BARRIERS GROWERS

FINANCIAL BARRIERS

For newer facilities, LEDs and other EE technology have become the default choice as they provide the lowest energy cost with long equipment life. For existing CEA facilities, the primary barrier to EE implementation is financial. Of the interviewed growers, all cited capital limitations as the primary barrier for not implementing any EE technologies. While each facility's profitability varies, on average the profit margins were noted to be too thin to invest any capital. Because of this, financial incentives for EE technologies would have a significant impact on technology adoption if they were able to reduce payback periods to meet grower requirements.

EDUCATIONAL BARRIERS

Another minor barrier that was observed through literature review and interviews is education. Some growers who use traditional HID or fluorescents are reluctant to change

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[31] See Section 5 for a summary of the market savings potential assumptions.

technologies for a variety of reasons, particularly due to concerns that any changes will negatively impact their product quality. Increased availability of educational opportunities for growers, particularly case studies of successful EE projects within the CEA market, will be beneficial for helping growers make informed decisions regarding energy consuming equipment.

MARKET BARRIERS FOR VENDORS

EDUCATIONAL BARRIERS

For vendors, the primary barriers preventing the adoption of EE technologies are educational and financial. CEA facilities are interested and aware of the energy saving benefits resulting from LEDs, high efficiency HVAC, and improved controls. Establishment of best practices for CEA growing and availability of case studies will allow vendors and designers to help growers design efficient systems that meet the growers' needs and give them the background knowledge to push back when growers have unreasonable expectations.

IOU FEEDBACK ON CUSTOMER BARRIERS

FRUSTRATION WITH IOU CUSTOM INCENTIVE PROGRAMS

There are multiple IOUs that provide incentives in various capacities to CEA facilities. These programs have varied in success based on their market, technology saturation, code, and effort put forth by the IOU. Multiple IOU stakeholders were interviewed who served both CEA and Cannabis customers through incentive programs across the USA to determine what were the common barriers were that impacted the performance of growers participating in the programs. With respect to California participation, the most common barrier is the customers frustration at the custom incentive program. This was echoed through multiple interviews due to how long the approval process requires, documentation necessary, influence hurdles, and lack of control of when the customer can purchase & implement their project. From the programmatic perspective, lighting has historically been classified a simpler measure to implement where a deemed/prescriptive offering has served the market. The project developers who work with CEA customers have a hard time developing engagement due to the challenges of participating in the existing program framework.

CUSTOMER EDUCATIONAL BARRIERS AND UNCERTAINTY

One of the larger barriers after engagement with a customer, is gaining customer interest in using EE technologies due to education on the product and the capital required. There are growers who believe that technologies such as LEDs will reduce their operating costs but are unsure on their impacts to their product quality. These comments did vary based on what crops the CEA facility produced with flowers & other non-consumable crops questioning the impacts of LEDs on quality of the plant's growth. While there are resources and available literature to show the impacts of LED lights on production, each grower makes their own independent decision for their facility.

RECOMMENDATIONS

ERI has compiled various studies, datasets, interviews, and publications to arrive at the following recommendations and next steps for SCE. It is important to note, that multiple standard practice documents and studies were reviewed and found variations from common practices, market adoption, and barriers that were not reflective of the interviews performed of California stakeholders. The follow technology practices are based on interviews with stakeholders and available data for Southern California.

SYSTEM STANDARDS AND EFFICIENT TECHNOLOGY

The follow sections will outline baseline recommendations for various technologies used within CEA facilities. These recommendations were selected using current market trends and interviewed stakeholders to arrive at these conclusions. While the market is under constant evolution, these recommendations reflect the most common and standard practice for existing CEA facilities in Southern California. It is also recommended to perform a detailed customer survey for each technology to determine the current market shares for a formal Industry standard practice determination.

INDOOR HORTICULTURE LIGHTING

As noted in previous sections, newer CEA facilities are using exclusively LEDs and advanced lighting controls. However, for existing CEA facilities the use of HID and fluorescent fixtures is very prevalent and used for all crop types. Based on a SCE study in 2019, the following table summarizes the recommended standard practice fixtures and percent of SCE market share. It should be noted that LEDs are used by 27% of all indoor growers, including cannabis, and that it is common for CEA facilities to use multiple lighting technologies. As of 2019, only 18% of CEA facilities use 100% LEDs and therefore are not standard practice.

TABLE 4. PERCENT OF SCE GROWERS USING LIGHTING TECHNOLOGY

LIGHTING TECHNOLOGY	PERCENT OF SCE GROWERS USING LIGHTING TECHNOLOGY
High Intensity Discharge (HPS, MH, CMH)	45%
Fluorescents (CFL, T5, T8, T12)	36%
LEDs	27%

All lighting systems are typically controlled with a simple or centralized controller that dictate the timing of the lights. Based on the literature review, there are known optimal lighting hours per day based on the stage of the plant’s life. This amount of time has an optimal value for each plant based on the growth cycle of the plant, PPFD produced by the lighting network, and other plant specific growth requirements. Due to these requirements, it is common practice to use a timer in the form of a centralized controller or simple electro-mechanical switch.

As technology advances LEDs design for indoor horticulture, the efficacy of these fixtures will increase and overall average PPE within the industry will rise. The average PPE on the DLC for LED fixtures is currently at 2.48 μmol/J which is significantly greater than the industry standards of HID and fluorescent fixtures at 0.8 to 2.0 μmol/J. It is not recommended to use PPE as standard practice or a baseline due to technology limitation and gap between LEDs and HID.

HVAC AND DEHUMIDIFICATION

One of the benefits of CEA facilities is the ability to control all aspects of the plant's growth from the amount of light received, water consumed, and temperature & humidity of the growing room. Within SCE territory, greater than 95% of all CEA facilities utilize ventilation with 59% using mechanical cooling and 24% with heating.

Based on interviews, the most common cooling & heating solution is in the form package DX units or mini splits. In the case of heating only, natural gas furnaces are used. The most common form of humidity control is a portable dehumidifier that can be purchased at most cannabis supply stores. It is important to size the dehumidification system, typically by pints of water removed per day, to ensure there is no vapor pressure deficit between the plants and air. Energy Star provides certifications to portable dehumidifiers using a metric of Liters per kWh which varies based on the number of Pints per day of water removed. summarizes the energy star standard for dehumidification.

TABLE 5. ENERGY STAR CERTIFICATION FOR PORTABLE DEHUMIDIFICATION [32]

EQUIPMENT	PRODUCT CAPACITY (PINTS/DAY)	INTEGRATED ENERGY FACTOR UNDER TEST CONDITIONS (L/KWH)
Portable Dehumidifiers	≤ 25.00	≥ 1.57
Portable Dehumidifiers	$25.01\ to\ 50$	≥ 1.80
Portable Dehumidifiers	≥ 50	≥ 3.30

Due to a wide range of dehumidification brands used, a more detailed assessment of Southern California growers' selection of dehumidification needs to be performed to determine the amounts that are Energy Star Certified.

HORTICULTURE CONTROLS

For CEA facilities, a centralized controller or energy management system (EMS) is used to integrate all systems from lighting, HVAC, CO_2, humidity, water, and plant sensor data. The control allows for scheduling, setpoint adjustment, automation, and monitoring of the plant's health or performance. Based on stakeholder interviews, a centralized BMS is very uncommon for growers in Southern California with only a small portion of larger growers utilizing them. This is due to their higher capital cost to install, experience needed to use effectively, and excessive number of data points in the eyes of the growers. In regard to EE, a centralized BMS allows for the ability implement various strategies to reduce energy consumption for lighting, HVAC, and water consumption.

The most common type of controller (>90% of growers) is a simple human-machine interface (HMI) to control lighting schedules and HVAC setpoints. Either in separate or a single controller, this provides the grower the easiest and cheapest method for adjusting and monitoring their systems operation. While a majority of the HMI's are touch screens, there are some customers who use electromechanical timers due to the reduced costs.

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[32] https://www.energystar.gov/products/appliances/dehumidifiers/key_efficiency_criteria

MARKET ADOPTION STRATEGIES

As outlined in previous sections, multiple barriers (noted by all stakeholders) are hindering EE adoption into the market. While some of these barriers have simple solutions, others are more complex and require acute attention to solve. The following sections will outline a collection of potential recommendations based on conservations with growers, vendors, and IOU representatives with experience in CEA programs. Not all recommendations will be ideal for Southern California Edison but will provide a holistic look at increasing the adoption rate of EE technologies for indoor agriculture.

EDUCATION AND MARKETING

LED technology for indoor agriculture is constantly evolving for improved efficacy (PPE), spectrums, and lighting output. In addition to the technology, there is significant research on the crops to determine the impacts of various light spectrums, temperature & humidity, and nutrient uptake. While some of these findings naturally make their way into the market, some of the fundamentals (such as impacts of LEDs on plant quality) are not yet fully accepted.

Multiple discussions with growers, vendors, and IOUs that have success in serving CEA facilities within incentive programs have identified that the primary reason for not adopting different technology is education. Growers are aware of the various technologies but have fears about their impacts and costs on the quality of their product. The following are recommended solutions:

- **Case Studies** – Producing case studies by real growers in Southern California territory will allow growers to see how others are using various technologies and their effects on product. It is recommended to select well known growers in the industry to reflect different technologies and experiences. This will empower other growers to adopt technologies such as LED lighting and detailed controls.
- **Open Houses & Workshops** – For other IOUs, providing growers the opportunities to come view the technologies at a customer site was shown to be beneficial. Based on conversations with IOUs who coordinated open houses to the market, they found great success in influencing customers to upgrade their facilities. One example of this has been document at Sacramento Municipal Utility District (SMUD) within their cannabis incentive program. Introducing workshops to these customers allows for an easier transfer of knowledge and development of trust with the IOUs.
- **Technical Documents & Marketing** – Based on grower interviews and IOU discussions, marketing directly to a subsector has been shown to increase responsiveness and program participation. While CEA facilities can participate the existing SCE custom program, targeted marketing will demonstrate the IOUs efforts to serve the market and will develop more trust in the technologies and savings potential.

INCENTIVES AND FUNDING

Providing incentives to CEA facilities has been viewed as the best method to promote both the adoption of EE technologies and incentive program participation. As described previously, the majority of CEA facilities without LEDs have strong interest in installing them but do not have the capital to spend. The customers have multiple options from private financing, accruing saving, replacing on fixture upon failure, or leveraging existing incentive programs. The current problem is the latter option has not been utilized significantly for existing facilities across California.

The existing IOU support for CEA customers consists of Rebates, Custom Incentives, and On-Bill Financing. Based on conversations with IOUs in California, the most activity from CEA customers has stemmed from New Construction with minor interest from existing customers. Based on interviews with stakeholders and successes from similar markets, the following are identified solutions for the CEA market:

- **On-Bill Financing** – Recently, IOUs have developed heightened interest in using financing for customers to implement EE technologies. As a majority of growers stated concerns with capital as a barrier to implement projects, leveraging the on-bill financing program with utility incentives has the potential to increase program participation.
- **Target Horticulture Lighting Rebates** – While LED lighting in California for commercial uses is approaching full industry standard practice (ISP) for both exterior and interior, LED lighting for non-vertical indoor growing is developing. While it may be challenging to get a workpaper approved (as LEDs for indoor growing can be complex based on canopy size and wattages), it would provide growers an easier method of participating in IOU programs. The challenges associated with getting LED workpapers approved include collecting sufficient customer data and meeting the DEER requirements for lighting set by the CPUC. A secondary option from a deemed approach would be a simplified or hybrid process that uses tools to calculate the incentive and savings. This would provide improved accuracy of savings with only minor additional inputs over the deemed approach.
- **Streamline the Custom Incentive Process** – During interviews with various IOUs, one of the major hurdles for engaging customers to participate in California incentive programs are the timelines and documentation required. CEA facilities are agricultural customers where their revenue generation is directly tied to their crop production and therefore the amount and quality are their largest concerns. Interviewed growers stated that the incentive program can take too long which results in reduced participation or withdrawal from projects. A more streamlined incentive process would line up with the customers implementation speed and improve overall satisfaction with the programs.
- **Normalized Metered Energy Consumption (NMEC) Program** – One of the most common challenges with incentive projects is developing a measurement & verification (M&V) plan for verifying lighting for a custom incentive project. Depending on the customers control system, this varies from challenging to simple but a majority of the time collecting logged data on the operating hours requires large numbers of loggers distributed throughout the growing area. During logging there are other challenges such as blocked sensors, relocated sensors, or changing of lighting levels that the loggers do not detect. An incentive program designed around the NMEC platform would make M&V quicker, simpler, and faster for customers to participate in the programs. Some challenges associated with NMEC would be model accuracy if the customer changes lighting schedules significantly.
- **Targeted Horticulture Incentive Rates** – Based on various grower interviews regarding investment criteria, more than 90% stated a simple payback approaching 1 year is needed to invest in EE. Due to the capital constraints of the market, without any incentive or other non-energy benefits, a majority of growers would elect not to implement any EE projects. It is recommended to increase incentive rates for horticultural lighting to a limit of a 1-year simple payback. This can be justified based on higher realization rates and net to gross values for indoor horticulture lighting projects. As an additional recommendation, the IOUs could require a commitment letter by the customer.
- **CEA Growing Technique** – Every different growing technique for CEA facilities have their pros and cons regarding energy consumption, yield rates, and maintenance. When a new facility is built, price is the primary driver in selecting the growing technique

which may result in a lower efficiency option for the growing area. It is recommended to asses' incentives to alter or change growing methods to a more efficient and less energy intensive. There may be some barriers to incentivizing such a broad opportunity such has cost effectiveness, higher incremental measure cost, and high simple payback. Some benefits of this approach are the ability to transform a market towards more efficient growing methods and techniques.

EMERGING TECHNOLOGIES

Due to decades of improvement within the CEA industry, there has been near constant technological advancement in LEDs, controls, and horticultural techniques. In addition, the CEA industry is also a global market with research being performed all over the world to drive EE. As a result, there are many emerging technologies that propose to revolutionize the industry through product quality or EE. The following technologies have been identified as potential key players in the future of indoor cannabis production.

LIQUID COOLED LEDS

In comparison to HPS fixtures, LEDs put out significantly less energy to heat which results in energy savings at a higher cost per fixture. However, air cooled LEDs still generate heat at the fixture that imparts extra load into growing area that needs to be conditioned by the HVAC system. Liquid cooled LEDs provide cooling to the components of the fixture which rejects the heat out of the growing area. The collected heat can be used for space conditioning, boiler pre-heating, radiant floor heating, and more. The resulting design has the capability to be more efficient than an air-cooled LED system but requires additional capital for the liquid infrastructure.

FIGURE 10. LIQUID COOLING LEDS

VERTICAL/STACKED FARMING

As described in previous sections, a majority of growers' main focus is to cultivate a cost-effective product in the space or building they have. The most common growing techniques used are hydroponics and soil in pot methods with suspended lighting. Within the indoor agriculture market for vegetables and leafy greens, the newest and cost-effective growing technique emerging is vertical or stacked growing. The benefit of vertical farming is the ability to produce more product per square foot in comparison to traditional indoor techniques.

Some factors that are slowing the adoption to indoor growing is the requirement to use LEDs as HPS or HID fixtures cannot be placed very close to the plant. Additionally, the infrastructure cost for the initial setup is greater than a more traditional hydroponic or soil in pot method which makes renovating existing facilities less cost effective.

FIGURE 11. VERTICAL/STACKED FARMING

INDOOR AGRICULTURE AUTOMATION

Unlike traditional outdoor agriculture, indoor growing provides the ability to control almost every element of the plant's growth from light, water, and nutrients. This allows the grower to fine tune the growth of the crop through manual adjustments my taking various measurements within the growing area. A new type of smart horticulture control is allowing growers to use distributed sensors throughout the growing area to automate the adjustments to the system. The controller allows for automatic control of heating, cooling, lighting, water, nutrients, humidity, and CO_2. The automated controls allow the grower to increase their production without having to increase their growing area.

SMART SENSORS AND AUTOMATION

With advancements in lighting technology, HVAC, and horticulture for indoor farming, controls have emerged as one of the more exciting advancements in the market. In conjunction with research on the crops' requirements, these advanced controls allow for micro adjustments to various systems to improve the quality and quantity of the products. In order to enable these controls, there have been advances in sensors to measure various growing parameters from soil temperature & PH, distributed CO^2, humidity, and temperature sensors, and various camera networks to monitor growth of the plants. Thanks to advances in large data analytics and internet-of-things (IOT) approaches, multiple companies are developing algorithms and methods to use this data to improve their operations. These advanced strategies are still in their infancy as the infrastructure is costly and only larger operations are exploring these technologies at this time. The end result will be more efficient and tuned CEA facilities to produce the highest quality produce with the lowest possible energy consumption.

CONCLUSION

The goal of this study was to identified barriers, solutions, and provide recommendations to improve the participating of CEA customers in SCE territory. As summarized in this section, there are multiple potential solutions, emerging technologies, and methods that SCE can adopt to improve their relationship, participation, and overall energy savings from CEA customers. Prior to implementing the following next steps, it is recommended for SCE to perform an internal audit of their CEA customers to develop a detailed characterization of the sector. This will help in characterization standard practices and growing techniques used throughout the SCE territory. The following steps are the recommended actions for SCE to implement that have been shown through this paper's research to be the most beneficial the IOU.

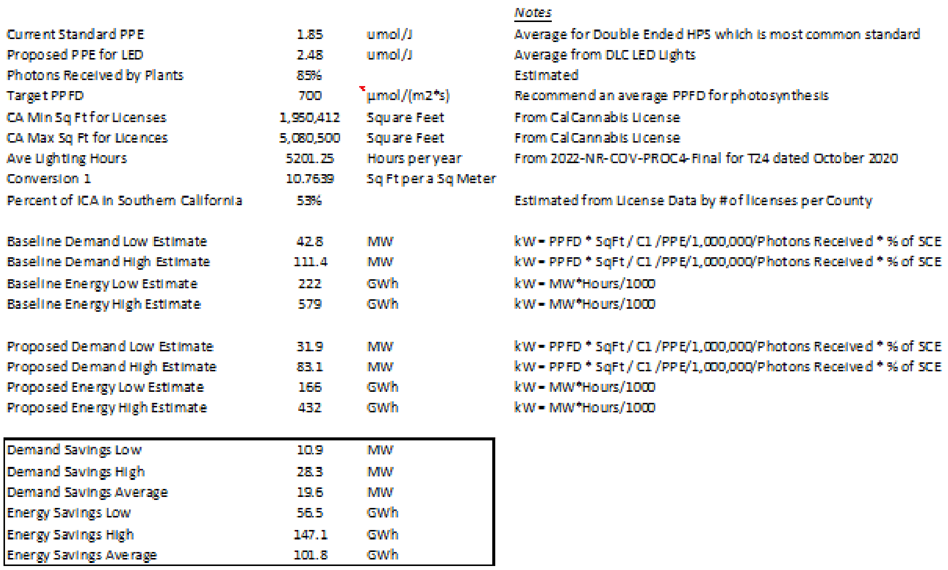
- **Program and Measure Development** – The challenges to the CEA industry identified through the research, surveys, and interviews in this study show that existing utility programs can be helpful in very specific circumstances for a very particular customer type. There exist opportunities to provide a range of interventions and incentive offerings for customers of various sizes and types of facilities. Emphasis can be placed on controls and holistic solutions to improve overall efficiency and ensure the energy consuming systems work optimally together.
- **Marketing & Customer Education** – Update SCE's marketing documentation to directly target indoor agriculture facilities with a diverse set of crops and growing techniques. This update will provide confidence in a wide range of CEA customers that the incentives are directly for them. The marketing documentation should also contain example project economics, technology details, case studies, and information for the customers to review internally. This ensures that customers are receiving the education they need and confidence to implement projects.
- **Utility Training** – Perform various training to utility staff who work directly and indirectly with indoor horticulture projects. This training will ensure all personnel have a clear understanding of the market, technologies, terminologies, and barriers that CEA customers face in the Southern California market. With an educated team with marketing materials, SCE will be better suited to help these customers participate in the program and receive utility incentives for equipment upgrades.
- **Simplify CEA Incentive Process** – There are many methods summarized above for simplifying the incentive process for CEA projects. For lighting projects, it is recommended to pursue a simplified or deemed calculation approach to improve the program participation. As a majority of CEA projects are centered around lighting, developing a workpaper or hybrid tool would be achievable with the aid of multiple standards such as the fixtures being on the DLC and baseline fixtures being HPS. If a deemed offering or hybrid tool are not feasible, it is recommended to implement a simple customized approach for CEA lighting projects to reduce turnaround time, meet customizers expectations, and provide flexibility around implementation schedules. This can be achieved but the use of a custom calculation tool, documentation checklists, and streamlined reports.
- **Modify CEA Incentive Rates** – It is recommended to customize the incentives provided for CEA lighting projects which will result in increased program interest while remaining cost effective. Due to the nature of lighting projects having a simple calculation methodology, the resulting realization rate for this measure type will be higher on average to improve the net-to-gross ration. When customized incentives are paired with streamlined calculation approach, the utility is able to provide more

resources to their customers to implement projects while maintaining a positive Total Resource Cost (TRC) for the program.

In addition to the outlined action items above, there are other steps that SCE can undergo to help better serve CEA customers. As sourced in the study, SCE performed an ISP assessment for CEA growers in Sothern California and found data supporting High Pressure Sodium fixtures as the most common for existing growers. It was also found the mechanical cooling was not common in all CEA facilities, but ventilation of the building was present for nearly all customer sites. The only item not covered was the use of dehumidification and what common practices SCE customers are using for the buildings. It is recommended to perform a survey of dehumidification technologies in SCE territory, as a potential work paper would be a cost-effective method to provide incentives to influence high efficiency dehumidification.

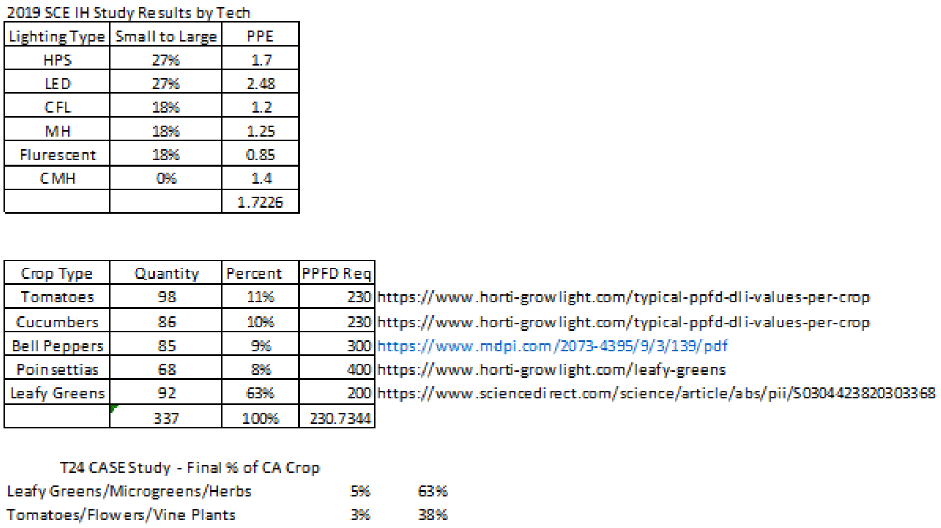
APPENDIX – A

MARKET POTENTIAL ASSUMPTIONS



			Notes
Current Standard PPE	1.85	umol/J	Average for Double Ended HPS which is most common standard
Proposed PPE for LED	2.48	umol/J	Average from DLC LED Lights
Photons Received by Plants	85%		Estimated
Target PPFD	700	µmol/(m2*s)	Recommend an average PPFD for photosynthesis
CA Min Sq Ft for Licenses	1,950,412	Square Feet	From CalCannabis License
CA Max Sq Ft for Licences	5,080,500	Square Feet	From CalCannabis License
Ave Lighting Hours	5201.25	Hours per year	From 2022-NR-COV-PROC4-Final for T24 dated October 2020
Conversion 1	10.7639	Sq Ft per a Sq Meter	
Percent of ICA in Southern California	53%		Estimated from License Data by # of licenses per County
Baseline Demand Low Estimate	42.8	MW	kW = PPFD * SqFt / C1 /PPE/1,000,000/Photons Received * % of SCE
Baseline Demand High Estimate	111.4	MW	kW = PPFD * SqFt / C1 /PPE/1,000,000/Photons Received * % of SCE
Baseline Energy Low Estimate	222	GWh	kW = MW*Hours/1000
Baseline Energy High Estimate	579	GWh	kW = MW*Hours/1000
Proposed Demand Low Estimate	31.9	MW	kW = PPFD * SqFt / C1 /PPE/1,000,000/Photons Received * % of SCE
Proposed Demand High Estimate	83.1	MW	kW = PPFD * SqFt / C1 /PPE/1,000,000/Photons Received * % of SCE
Proposed Energy Low Estimate	166	GWh	kW = MW*Hours/1000
Proposed Energy High Estimate	432	GWh	kW = MW*Hours/1000
Demand Savings Low	10.9	MW	
Demand Savings High	28.3	MW	
Demand Savings Average	19.6	MW	
Energy Savings Low	56.5	GWh	
Energy Savings High	147.1	GWh	
Energy Savings Average	101.8	GWh	

FIGURE 12. MARKET POTENTIAL ASSUMPTIONS 1



2019 SCE IH Study Results by Tech

Lighting Type	Small to Large	PPE
HPS	27%	1.7
LED	27%	2.48
CFL	18%	1.2
MH	18%	1.25
Flurescent	18%	0.85
CMH	0%	1.4
		1.7226

Crop Type	Quantity	Percent	PPFD Req	
Tomatoes	98	11%	230	https://www.horti-growlight.com/typical-ppfd-dli-values-per-crop
Cucumbers	86	10%	230	https://www.horti-growlight.com/typical-ppfd-dli-values-per-crop
Bell Peppers	85	9%	300	https://www.mdpi.com/2073-4395/9/3/139/pdf
Poinsettias	68	8%	400	https://www.horti-growlight.com/leafy-greens
Leafy Greens	92	63%	200	https://www.sciencedirect.com/science/article/abs/pii/S0304423820303368
	337	100%	230.7344	

T24 CASE Study - Final % of CA Crop

Leafy Greens/Microgreens/Herbs	5%	63%
Tomatoes/Flowers/Vine Plants	3%	38%

FIGURE 13. MARKET POTENTIAL ASSUMPTIONS 2

SUMMARY OF INTERVIEW QUESTIONS

INDOOR AGRICULTURE SURVEY FOR INDUSTRY ASSOCIATION

Please answer the following questions to best of your knowledge:

1) Within California, have you observed a change in the number of indoor agriculture facilities over the last several years?

2) What are the primary reasons for growers choosing indoor over traditional agriculture?

3) What do you think are the primary reasons for any industry-wide trends towards or away from indoor agriculture?

4) From highest (1) to lowest (4), rank the prevalence of lighting technology in indoor agriculture facilities.
    ___ Incandescent
    ___ Fluorescent
    ___ LED
    ___ HPS
    ___ MH

5) Why do growers typically choose traditional lighting technologies over LEDs?

6) From highest (1) to lowest (4), rank how common each cooling system technology is among indoor agriculture customers.

___ DX Package Units
___ Water-source heat pump
___ Split system AC/heat pump
___ Hydronic (chiller) system

7) What are the primary drivers behind cooling system choice?

8) Besides Lighting, HVAC (including circulation fans and dehumidifiers), and water pumping, is any other major energy using equipment common at indoor agriculture sites?

9) Are there any formal guides or classes regarding indoor agriculture best practices (with regards to lighting, cooling, heating, water use, etc.)?

10) What, in your opinion, are the primary barriers to the adoption of energy efficient technologies (i.e., LED lighting, high efficiency HVAC, motor VFDs) in indoor agriculture?

11) What, in your opinion, could be done to increase the prevalence of energy efficient technologies in indoor agriculture?

INDOOR AGRICULTURE SURVEY FOR CULTIVATORS

Please answer the following questions to best of your knowledge:

1) What are the most common crops being cultivated in the indoor farms?

2) Could you provide an estimate of how much is produced by the indoor farm annually (lbs./ft^2)?

3) Has there been an increased demand in indoor agriculture cultivation in recent years? How much and what is the main reason for its growth?

4) What percent of facilities were in each size range?

<10,000 Ft^2 10,000 to 50,000 Ft^2 >50,000 Ft^2

5) From most common (1) to least common (4) rank the prevalence of the following horticulture set-ups.

___ Soil
___ Hydroponics
___ Aeroponics
___ Vertical Farming
___ Other _______________

6) From most common (1) to least common (6) rank the prevalence of HVAC System set-ups in the facilities being cultivated.

___ Packaged DX Units
___ Evaporative Cooling
___ Natural Ventilation
___ Split AC
___ Hydronic Systems
___ Heat Pumps

7) From most common (1) to least common (4) rank the prevalence of lighting fixture set-ups.

___ Incandescent
___ Fluorescent
___ LED
___ HPS
___ CMH
___ Other _______________

8) What is the typical lighting density for crop growth in indoor farms (fixtures/ft^2)?

9) What are the biggest barriers that you have observed when it comes to adopting energy efficiency in lighting, HVAC systems, and other equipment used in indoor farming?

INDOOR AGRICULTURE SURVEY FOR GROWERS

Please answer the following questions to best of your knowledge:

1) What plants are being grown at the facility?

2) What is the total area of the facility that is dedicated to growing (ft^2)?

3) Was the facility a new construction or a renovated existing facility?

☐ New Construction
☐ Renovated Facility

4) What kind of horticulture is used to nourish the plants?

☐ Soil
☐ Hydroponics
☐ Aeroponics
☐ Vertical Farming
☐ Other ________________

5) How much of the crop does the facility produce annually (lbs./year)?

6) What type of lighting does the farm use for crop photosynthesis?

☐ Incandescent
☐ Fluorescent
☐ LED
☐ HPS
☐ CMH
☐ Other ________________

7) What wattage and how many lighting fixtures are used for growing in the facility?

8) How much water does the facility consume annually (gallons/year)?

9) What was the annual electrical energy (kWh) and average maximum demand (kW) over the last 12 months?

10) How many pumps are used to supply water to the crops? What is the average pump size (HP) and the number of hours it operates throughout the day?

11) Which Cooling technology is used in the growing area?

☐ Packaged DX Units
☐ Evaporative Cooling
☐ Natural Ventilation
☐ Split AC
☐ Hydronic Cooling
☐ Heat Pumps
☐ Other ________________

12) Which heating technology is used in the growing area?

☐ Electric Boiler/Heaters
☐ Gas Boiler/Heaters
☐ Heat Pumps
☐ Combined Heat & Power (CHP)
☐ Other _______________

13) What is the regular temperature, relative humidity %, and CO2 concentration respectively in the room during production?

14) What is the main reason that customers prefer indoor farmed products over conventionally farmed ones?

15) What is the main obstacle that the farm is facing relative to conventional farming?

16) Other than plant requirements, what was the biggest factor that helped you select the equipment in your facility today (e.g., cost, energy consumption, ease of use)?

17) What kind of energy efficient technologies does the facility use onsite (e.g., VFDs, LED controls, CO_2 sensors)?

18) What are your primary concerns with implementing energy efficiency upgrades?

☐ Initial Costs
☐ System Performance
☐ Training Needed for New Systems
☐ Manpower Required for Procurement and Installation
☐ Other __________________

19) If an energy efficiency project is proposed which involves retrofitting existing equipment to reduce energy consumption & costs, what is an ideal payback period that you are willing to consider for the project?

☐ <1 year
☐ <2 years
☐ <5 years
☐ <10 years

INDOOR AGRICULTURE SURVEY FOR LIGHTING VENDORS

Please answer the following questions to best of your knowledge:

1) Where are most of your clients located in California? Outside California?

California (north, central, south, etc.,): ______________________________

Locations Outside CA (East, south, etc.): _______________________________

2) In terms of indoor farm area, approximately what percent of customers were in each range (ft^2)?

___% <10,000 Ft^2
___% 10,000 to 50,000 Ft^2
___% >50,000 Ft^2

3) What percentage (%) of your customers purchase for new builds, retrofit, or to upgrade?

___ % New build
___ % Retrofit
___ % Upgrade

4) For indoor agriculture customers, which fixture is purchased the most (1) to least (6).

___ Incandescent
___ Fluorescent
___ LED
___ HPS
___ CMH
___ Other _________________

5) What is the main driver(s) for growers' selection of lighting, racks, and control systems?

☐ Price
☐ Ease of use
☐ Specific crop requirements
☐ Electricity consumption

☐ Other ______________________

6) What is the average lighting density (lamps/square feet) or (lumens/square feet) or photosynthetic photon flux density (PPFD) purchased by indoor agriculture customers?

7) What types of controls are indoor agriculture customers purchasing with their lights (i.e., manual on/Off, timer, photosensor, light spectrum controls, etc.)? and how many controls are needed to run the grow lights?

8) In the last five years, how has the use of lighting in indoor agriculture been trending (i.e., type of lights used, number of fixtures, type, or expertise of customers, etc.)?

9) What are the barriers to customers selecting LED tech and controls in their facilities either for new builds or retrofits/upgrade?

10) What can be done within your industry to increase adoption by your customer base of energy efficient tech?

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