RESOURCE INNOVATION INSTITUTE

Efficient Yields
Best practices on energy, water efficiency, and productivity

Lighting Best Practices for Efficient Indoor Agriculture

In partnership with

SOUTHERN CALIFORNIA EDISON

October 18, 2022

Agenda

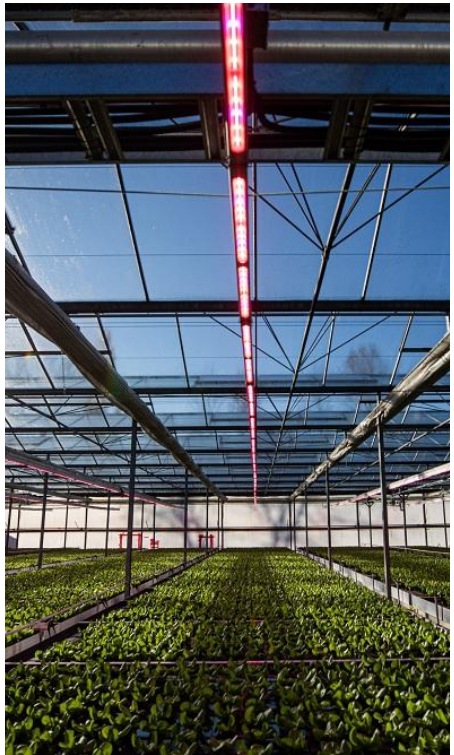
Introduction & Purpose	1:30 pm
How CEA Crops Use Light	
Benefits of Using LED Lighting	
Optimizing Lighting System Design	
Maximizing Financial Incentives for CEA Lighting	
LED Lighting Best Practices for Vertical Farming	
Considerations for Lighting Controls	
Commissioning Sole-Source Lighting Controls	
Benchmarking Lighting System KPIs	
SCE New Lighting Incentives	
Efficiency Program Examples	
Q&A	2:45 pm

SECTION 01

INTRODUCTION & PURPOSE

About RII

- Objective, data-driven non-profit
- Founded 2016 in Portland, Oregon
- Expertise in climate policy, utility programs, green building certification, sustainable business, construction & indoor cultivation
- In 2020, received 3-year grant from USDA to develop KPIs, standards & building rating system for CEA



What We Do / Our Mission

We measure, verify & celebrate the world's most efficient agricultural ideas.

Measure

Efficiency & Productivity

- Key Performance Indicators
- Benchmarks
- Baselines

Verify

Best Practices & Standards

- Training
- Policies
- Utility Programs

Celebrate

Leadership Recognition

- Verification
- Case Studies
- Certification

Our Network

INPUT from industry leaders and partners

RESOURCE INNOVATION INSTITUTE

EDUCATION and advocacy about best practices for growers

RII Technical Advisory Council

Multi-disciplinary body who aggregates knowledge to support producers and other stakeholders with objective and peer-reviewed data and curriculum on benchmarking resource efficiency

- **Guides** development of standards
- **Shapes** tools and resources to support best practices
- **Advocates** for informed policies, incentives and regulations

HVAC - Lighting - Utility - Water
Policy - Data - Controls - Emissions
Facility Design & Construction

ABOUT US

Peer-Reviewed Publications

Best Practices Guides
for Producers

Best Practices Guides
for Governments and Utilities

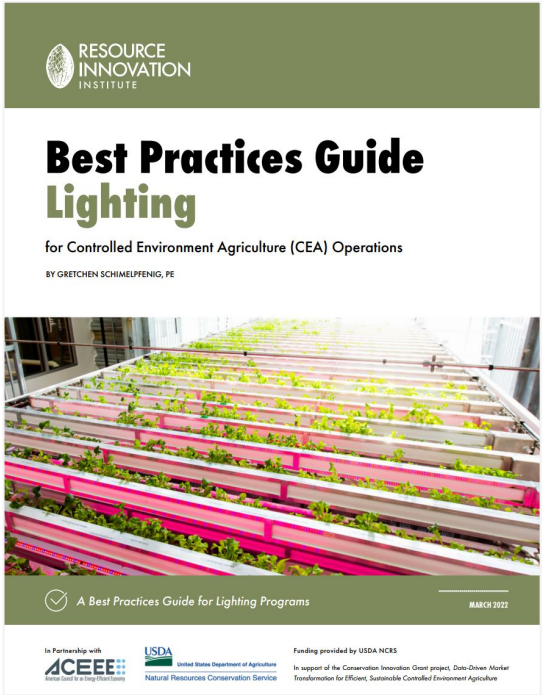
Industry Reports
on Resource Usage

Download the Lighting Best Practices Guide

Brand-agnostic information for producers

Free guidance on lighting

- Speaking the language of horticultural lighting
- Reviewing manufacturer's literature to evaluate your purchasing options
- Understanding crucial considerations when selecting LED lighting
- Installing and operating successful LED lighting solutions in alignment with your business model
- Funded by the: USDA United States Department of Agriculture, Natural Resources Conservation Service



DOWNLOAD NOW

Today's Speakers

Rob Eddy

RESOURCE INNOVATION INSTITUTE

Kenda Branch

HAWTHORNE GARDENING CO

Casey Rivero

FLUENCE

Kasey Holland

DLC

California Cannabis Landscape

- Licenses
  - Specialty cottage
  - Specialty
  - Small
  - Medium
  - Large (2023)
  - Nursery
  - Processor
- Outdoor
- Indoor
- Mixed-light
  - Tier 1 – Up to 6 watts per square foot
  - Tier 2 – 6 to 25 watts per square foot
- 4 Billion legal market

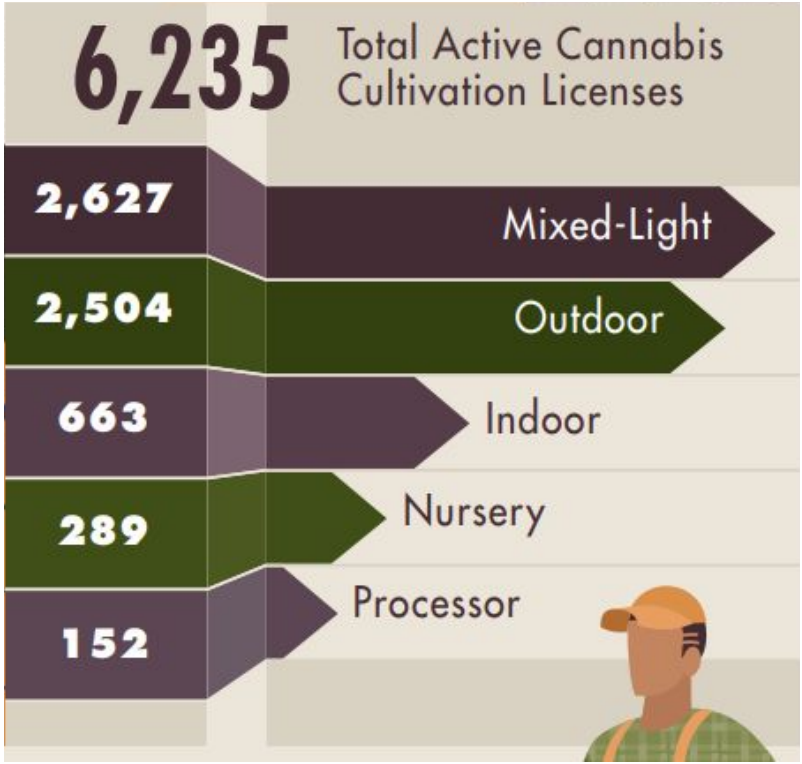


Image credit: CDFA 2020.

California CEA Landscape

- Food
  - Most area dedicated to CEA
  - Largest tomato growing area
  - Largest berries growing area
  - Largest other veg growing area
  - 2nd largest mushroom growing area
- Floriculture
  - Second only to Florida
  - Largest nursery stock crop area
  - 2nd largest cut flowers area

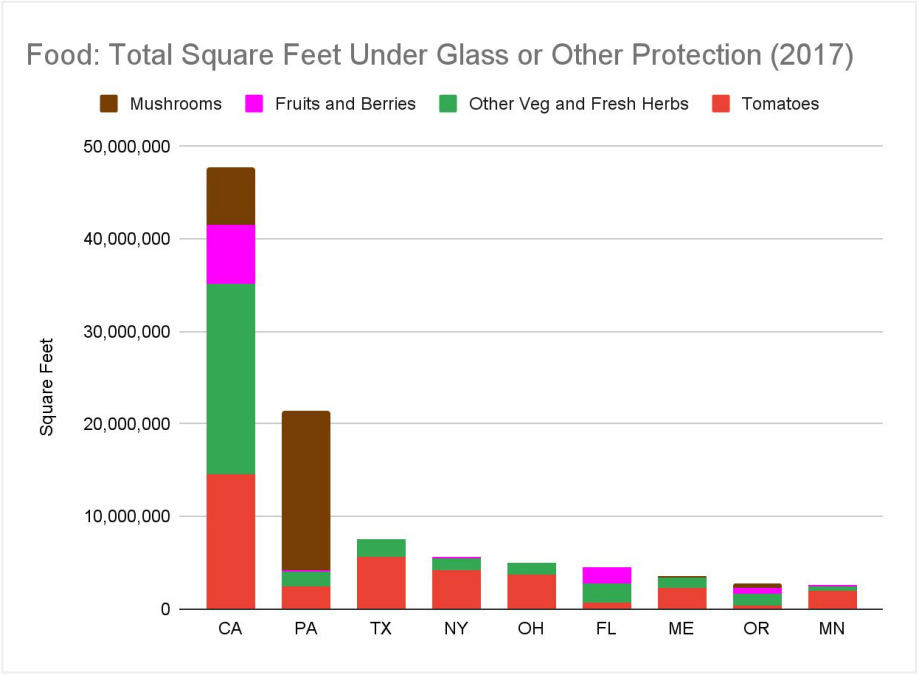


Image Credit: RII CEA Market Transformation Strategy & Implementation Plan. Data credit: USDA 2019 Ag Census

Purpose of Today's Workshop

- Encourage cultivators to participate in SCE and California efficiency programs

- Convey scientific insights and industry expertise directly to producers and find the best ways to translate them in the context of their local ecosystem.

- Help energy efficiency programs achieve their savings goals through education and knowledge sharing

Efficient Yields
Best practices on energy, water efficiency, and productivity

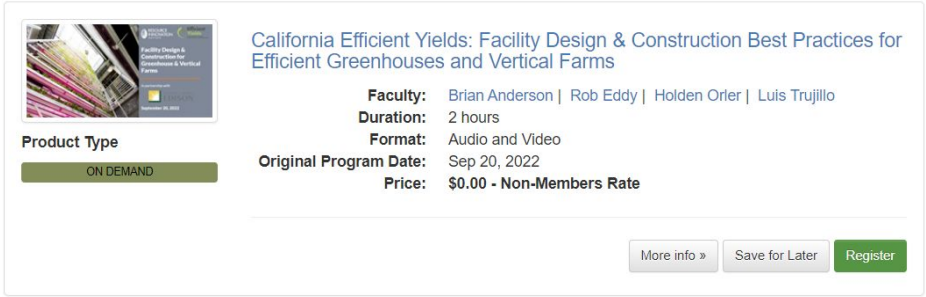
Access Your California Virtual Classroom

Continue Learning Online

Free guidance on efficient cultivation

All live workshops are available for on-demand viewing!

- Recordings of live workshops
- Tip Clips
- Downloadable resources
- SCE, PG&E and state program tools

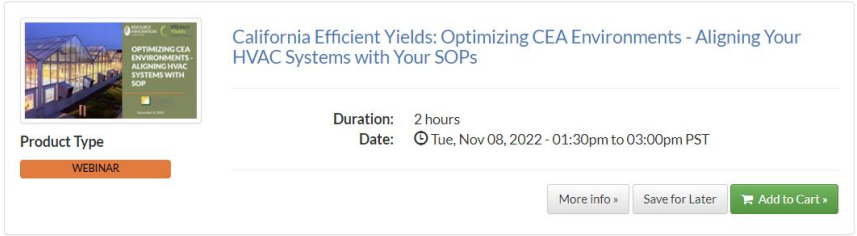


Create an account at
resourceinnovation.org/California

Register for Upcoming Workshops

Optimizing CEA Environments - Aligning Your HVAC Systems with Your SOPs

November 8, 2022



Controls & Automation Best Practices for Efficient Greenhouses and Indoor Agriculture

December 13, 2022

Register and access other free resources at the

RII catalog

SECTION 02

HOW CEA CROPS USE LIGHT

Understand Spectra (SQD)

Target Ranges for Best Outcomes for Plants

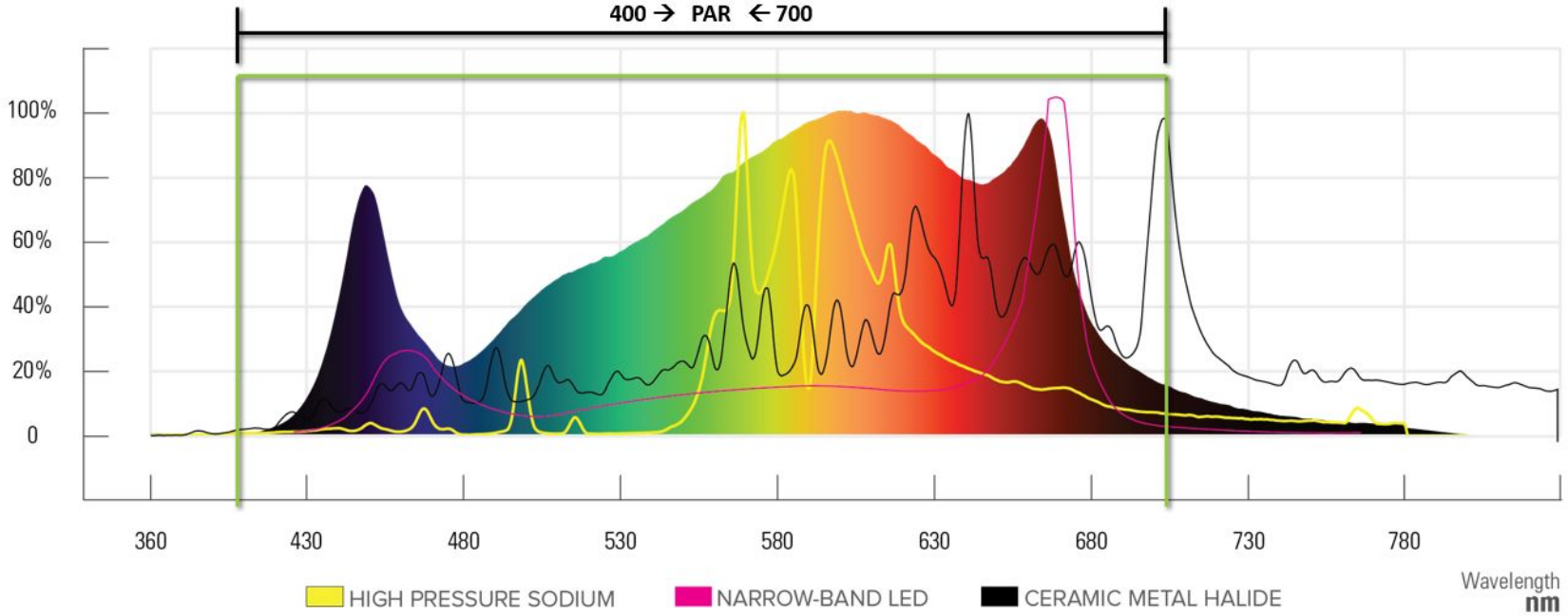


Image credit: Fluence

Key Terms for Plants

Measuring Light Received by Crops

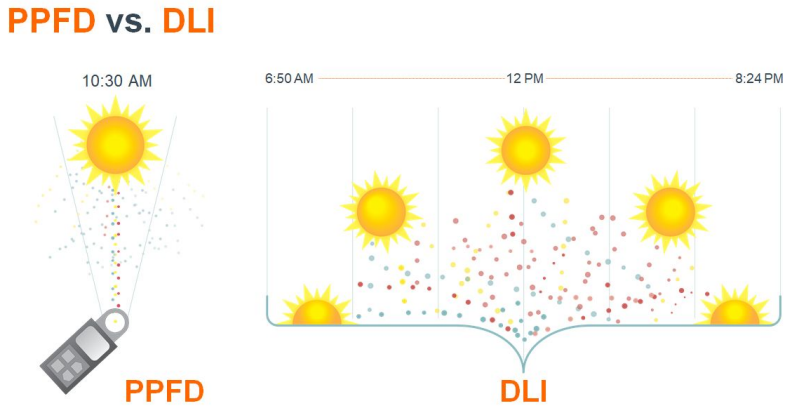
- PPFD measures instantaneous light intensity
- DLI measures amount of light over time

PPFD – Photosynthetic Photon Flux Density: the amount of PAR that actually arrives at the plant, or the number of photosynthetically active photons that fall on a given surface each second (µmol/ m^2/s)

Measures light intensity, like lux or footcandles

DLI – Daily light integral: the number of photosynthetically active photons (photons in the PAR range) per square meter per day (µmol/ m2/day)

Equal to the sum of PPFD over the course of the day



Understand Photoperiods

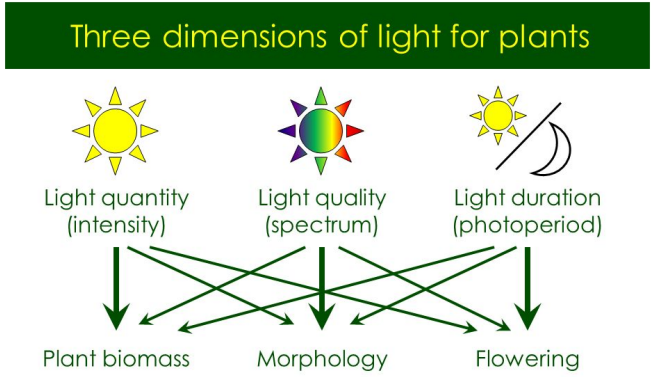
Scheduling Light Treatments for Crop Growth

Photoperiod: the period of time each day during which an organism receives illumination

Long-day plants: Plants that **bloom when they receive more than 12 hours of light**, like summer blooming flowers and garden veggies like lettuce

Short-day plants: Plants like cannabis and fall flowering plants like poinsettia that **form flowers only when day length is less than 12 hours**

Phototropism: the orientation of a plant in response to light (shade avoidance, elongation, stretch)



The different properties of light interact to control yield and quality attributes of plants

Image credit: Dr. Erik Runkle, Michigan State University

“Light Recipes”

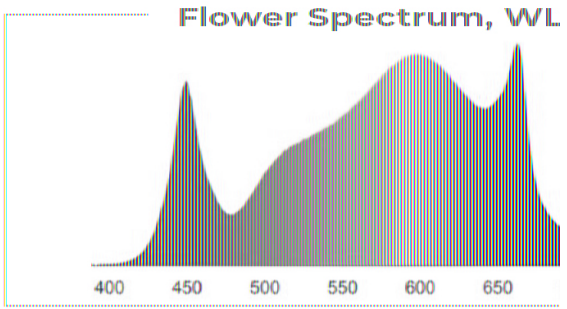
Target Ranges for Best Outcomes for Plants

Light recipe: polychromatic spectrum made up of different LEDs with specific red:blue (R:B) and red:far red (R:FR) ratios

Phytochrome photostationary state: far red light informs plants about shade and increased far red light simulates shade

Example: an “R4” fixture might have 40% red diodes and an R8 fixture might have 80% red diodes

Example: a “FR” fixture might have a PSS value of 0.78 or 0.86



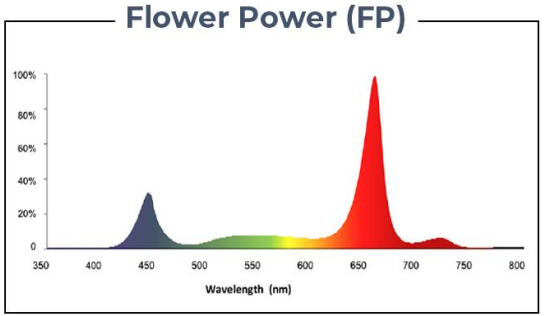


Image credit: TSRgrow

Effects of Wavelength on Plant Growth

Light	Wavelength (nm)	Major Processes	Notes
UV-C	100 - 280	Secondary metabolism	Useful for pathogen control
UV-B	280 - 315	Secondary metabolism, shade avoidance, phototropism	Affects (often increases) metabolites and defensive compounds; high levels disrupt growth
UV-A	315 - 400	Secondary metabolism, photomorphogenesis	
Blue	400 - 500	Photosynthesis, shade avoidance, phototropism, secondary metabolism	Some level necessary for optimal photosynthesis
Green	500 - 575	Photosynthesis, shade avoidance, secondary metabolism	Able to penetrate further through canopy than blue/red
Yellow / Orange	575 - 610	Photosynthesis, secondary metabolism	Using these wavelengths can increase growth and metabolites; results vary between species
Red	610 - 700	Photosynthesis, shade avoidance, photoperiodism, secondary metabolism	Highest action spectrum for photosynthesis; important to consider ratio of red to far-red (R:FR)
Far-red	700 - 800	Photosynthesis, shade avoidance	Enhances photosynthesis; consider R:FR

Image credit: RP-45-21, Illuminating Engineering Society

Lighting Impacts Growing Environments

Lighting Interactive Effects

- Ambient conditions can affect demand for lighting (schedule and intensity)
  - Greenhouses have dynamic temperature, humidity, CO_2

Systems Affected by Lighting

- HVAC and humidity management
- Fertigation
- Curtain controls

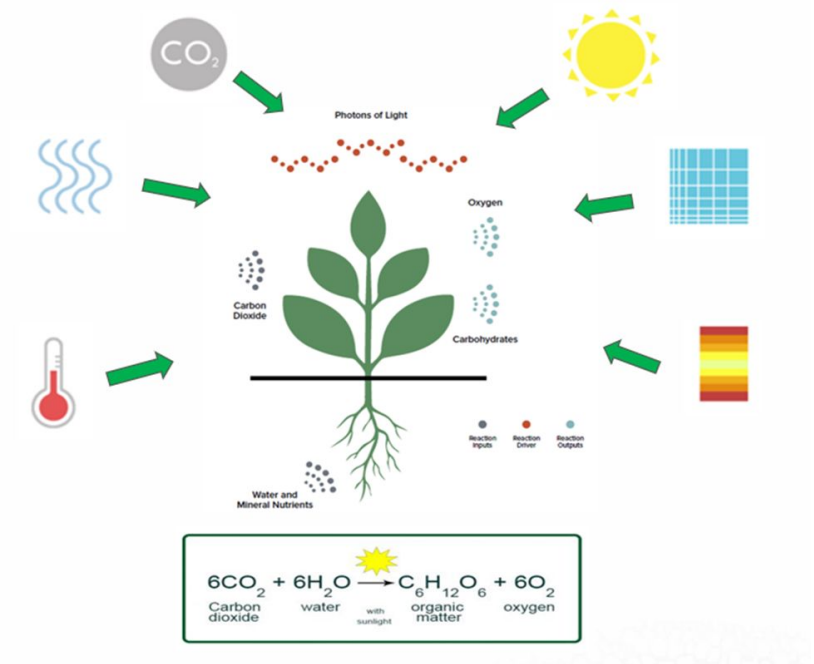


Image credit: Fluence

SECTION 03

BENEFITS OF LED LIGHTING

Benefits of LED Lighting

- **Energy Efficiency & OpEx**
  - More output with fewer watts
- **Financial Incentive Programs / Rebates**
- **HVAC Interactive Effects**
  - Heat load & environmental control
  - Less watts = less heat = less AC
- **Operation**
  - Spectrum, controllability, dimmability, precision chemistry
- **Maintenance & Business Benefits**
  - Durability & lifetime

Energy Savings Potential of LED Lighting Technology

Energy-Saving Lighting Solutions	Energy Savings Potential
Horticultural Lighting Systems: • Air-cooled LED light fixtures • Liquid-cooled LED lighting systems • LED lamps • Lighting controls	30 - 40%

Figure data source: RII CEA Market Characterization Report, 2021

Save Energy and Reduce Utility Bills

Higher PPE, Lower Energy Demand, Lower Energy Bills

- Fluorescent horticultural lighting systems (like T8)can achieve PPE ranges of
  - 0.7 - 1.2 µmol/J
- HID horticultural lighting systems (like HPS) can achieve PPE ranges of
  - 1.0 - 1.7 µmol/J
- LED horticultural lighting systems can achieve PPE ranges of
  - **1.8 - 3.0 µmol/J**
- **Evaluate options based on total PPF delivered to a space**

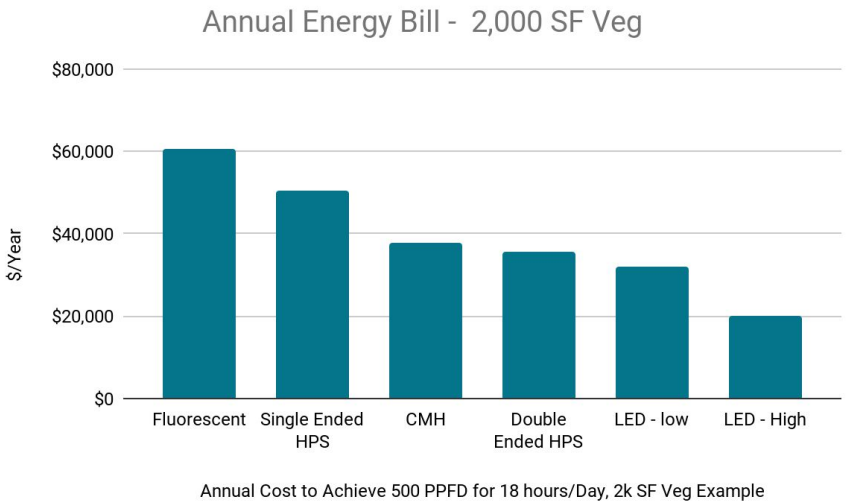


Figure data source: Seinergy LLC

Compliance with Title 24 Code Changes

CALIFORNIA ENERGY CODES & STANDARDS
A STATEWIDE UTILITY PROGRAM

Read the Final CASE Report

CEA Growing, Horticultural Lighting

In a building with CEH spaces and with more than 40 kW of aggregate horticultural lighting load, the electric lighting systems used for plant growth and plant maintenance shall meet the following requirements:

1. Luminaires shall have a photosynthetic photon efficacy of at least ***1.7 (greenhouses), 1.9 (indoor) micromoles per joule*** rated in accordance with ANSI / ASABE S640 for wavelengths from 400 to 700 nanometers.

2. Time-switch lighting controls shall be installed and comply with Section 110.9(b)1, Section 130.4(a)4, and applicable sections of NA7.6.2.

3. Multilevel lighting controls shall be installed and comply with Section 130.1(b).

Affect HVAC System Capacity

LED Lighting Affects Sensible Heat Loads

Cultivation operations use HVAC systems sized for both latent (wet) and sensible (dry) heat loads

Heat from lighting systems adds to sensible loads

LED horticultural lighting systems put out less heat than HID lighting systems

- Lower HVAC loads means facility HVAC system HVAC capacity can be reduced (depending on the types of equipment used for heating, cooling, and dehumidification)
- Downsizing HVAC equipment can result in up to **33% lower HVAC system capital costs** and help fund higher upfront costs of LED lighting systems
- Smaller HVAC equipment can also reduce recurring operating costs for environmental management

Image credit: Agnetix

Operate Differently

Change the Way You Grow

- Mount closer to your crop canopy and provide higher light intensities with better uniformity
- Grow vertically in racking systems
- Growers can meet target PPFD with less fixtures, freeing up capital for other investments.
- No bulbs to change but boards of diodes to maintain
- LEDs can be cycled on and off and ramped up and down easily and with precise granularity
- LED fixtures capable of dimming can provide your crop canopy with exactly as much light as they need

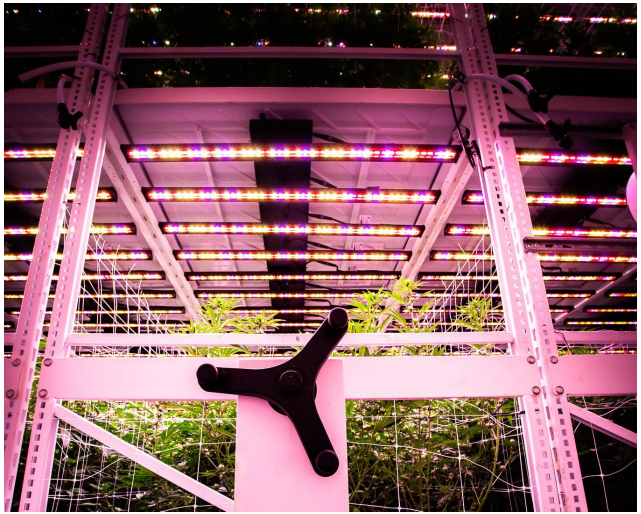


Image credit: TSRgrow

Maintain Differently

Change Labor Utilization for Lighting

- No bulbs to change but boards of diodes to maintain
- LED can maintain light output for longer than traditional horticultural lighting solutions like HID
- LED fixtures can be rated for ingress protection (IP), which means they are vapor tight for safe application of sprays for integrated pest management and fixture hose-down for cleaning

Image credit: TSRgrow

Review Certified Equipment

Use DesignLights Consortium QPL

- Visit https://qpl.designlights.org/horticulture
- Filter by PPE
  - Choose a minimum and maximum PPE
  - Understand that fixtures with high PPE may be more expensive
  - 3.6 - 3.8 umol/J is the upper bound for fixtures in for attractive grower ROI and may have high amounts of red diodes
- State Compliance filter for businesses operating in states with minimum PPE requirements (MA, IL, soon to be CA)

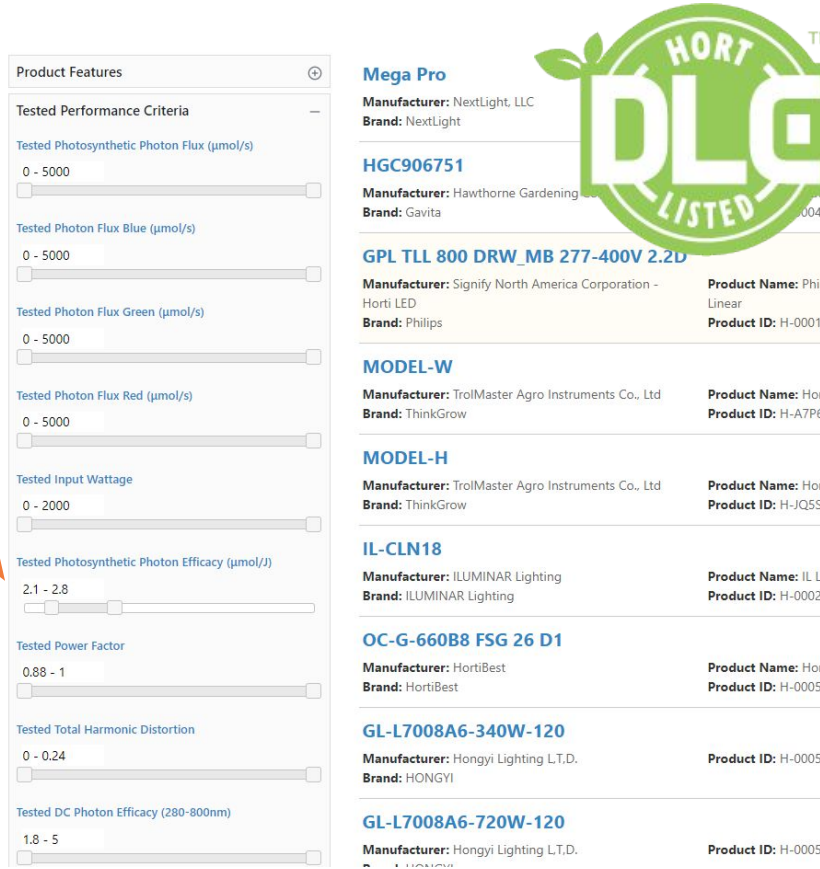


Image credit: DesignLights Consortium Horticultural QPL, accessed February 2022

Steer Crops

Light Affects Yield & Quality

- LEDs provide adequate light levels and specialized light recipes for plants
- Plants grown with LEDs can produce similar or better yields than those grown with other lighting technology
    - 1% increase in light intensity correlates to 1% increase in yield
- Lighting systems operated with customized and/or tunable spectra can improve crop quality
- Spectral treatments can impact taste, structure and pigments of fruits and can help with pathogen management
- Spectral treatments also have impacts on harvested yield

Image credit: Signify

SECTION 04

OPTIMIZING LIGHTING SYSTEM DESIGN

LED Lighting Features

Not all LEDs are created equal

- Application
- Photometrics
- Ballasts and Drivers
- Dimming and Controls
- Maintenance
- Warranty
- 3rd Party Certification

Image credit: DLC, Hawthorne

Lighting Trends

From the growers

- Majority growing indoors
- Managing energy costs one of the main concerns
- Boost in multi-tier operations
- More require dimming capabilities
- Higher light intensity asks
- Concern about light spectrum

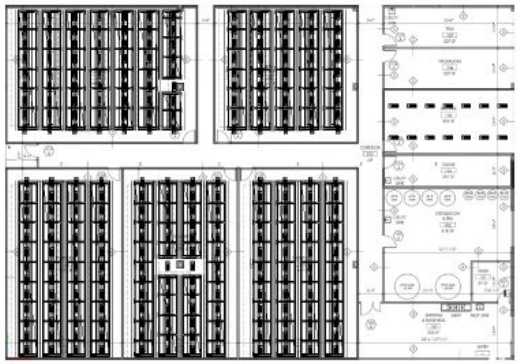
Provide plants with the exact intensity and quantity of light while minimizing energy consumption and lowering bills

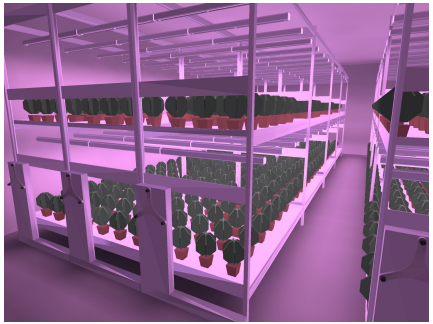
Image credit: DIALux Evo, Hawthorne

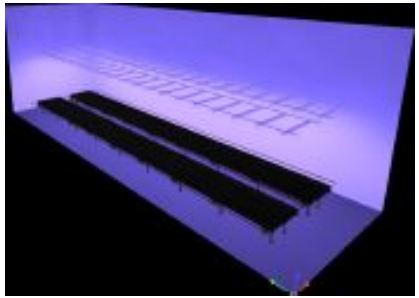
3D Modeling

Designs can include and confirm:

- Site plans
- Fixtures
- Hardware
- Color rendering
- Retrofit options







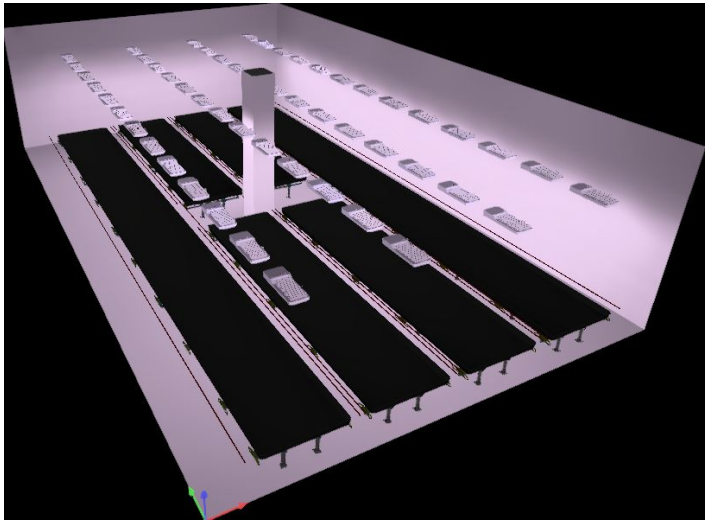


Image credit: DIALux Evo, Hawthorne

2D Mapping

Layouts can include and confirm:

- Average PPFD and uniformity
- Heat maps and isolines
- Dimensions, spacing, and coordinates
- Total Wattage, current, and heat load
- Fixture Specs

Fixture	Gavita Pro 1930e LED 120-277V	
Part #	HCC906740	
Voltage	120-277	V
Power	780	W
Current	2.8 - 6.5	A
Heat Load	2661	BTU/hr

Number of Fixtures	98	pcs
Fixture Bottom	9.25	ft
Calculation Surface 1 (Max crop + bench)	6.67	ft (from floor)
Ave PPFD	1000	µmol/m2-s
Uniformity	90	%
Calculation Surface 2 (Min crop + bench)	3.67	ft (from floor)
Ave PPFD	931	µmol/m2-s
Uniformity	68	%
Bench Height	20	in
Wattage / Room	76.44	kW
Current / Room @277V	276	Amps
Heat Load / Room	260.81	kBTU/hr

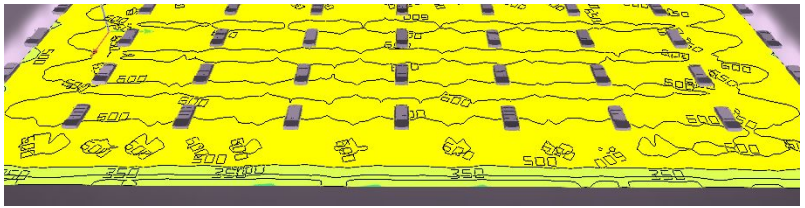


Image credit: DIALux Evo, Hawthorne

SECTION 06

MAXIMIZING FINANCIAL INCENTIVES

Financial Considerations

- Crop type and market needs
- Business model
- Space utilization
- Capex/ Opex
- Payback period and ROI

Image credit: Fluence

Indoor Lighting Strategies

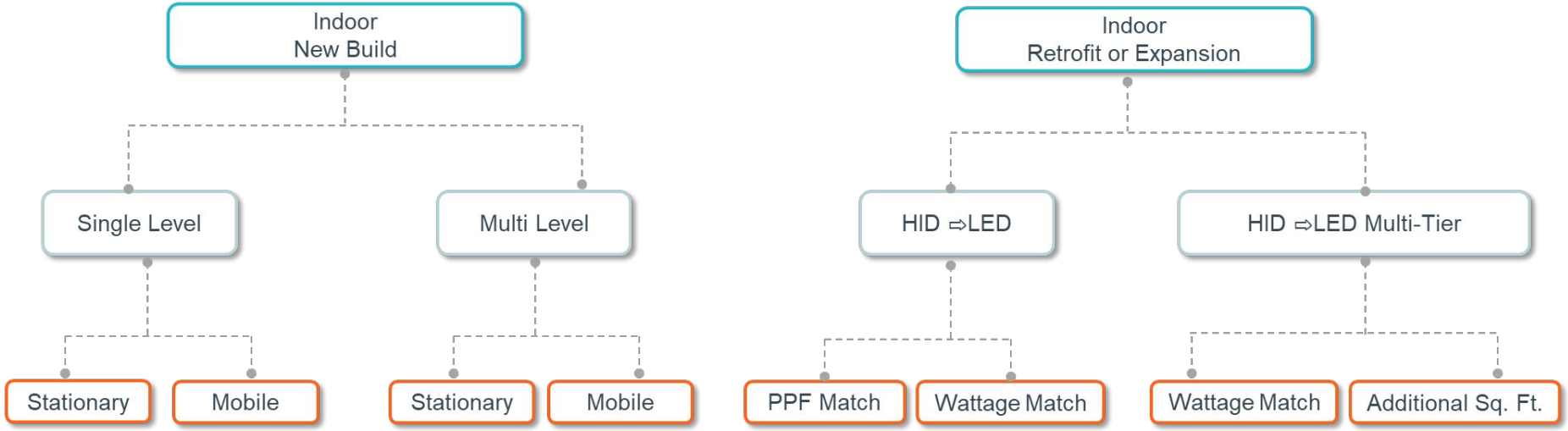
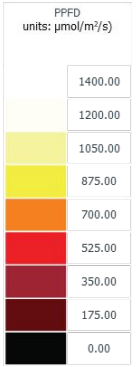


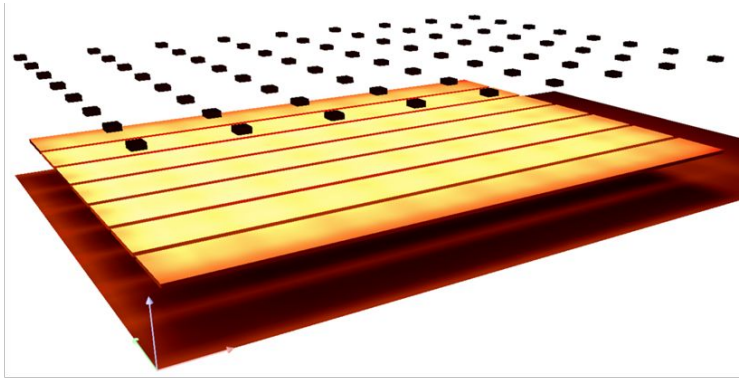
Figure credit: Fluence

HID ⇨ LED

1:1 Retrofit

Metric	HPS	LED	Δ
Fixture Quantity	72 DE HPS 1000W	72 VYPR 2p	Match
Room PPF	126,000 µmol/s	122,400 µmol/s	-2.86%
PPFD Average	888 µmol/m²/s	889 µmol/m²/s	+ 0.11%
Total Electrical Input	75,600 watts	45,360 watts	- 40%
Lighting Power Density	67.5 w/ft²	40.5 w/ft²	- 40%
Fixture Mounting Height	3' from Canopy	3' 6" from Canopy	NA
Canopy	1,120 ft²	1,120 ft²	Match





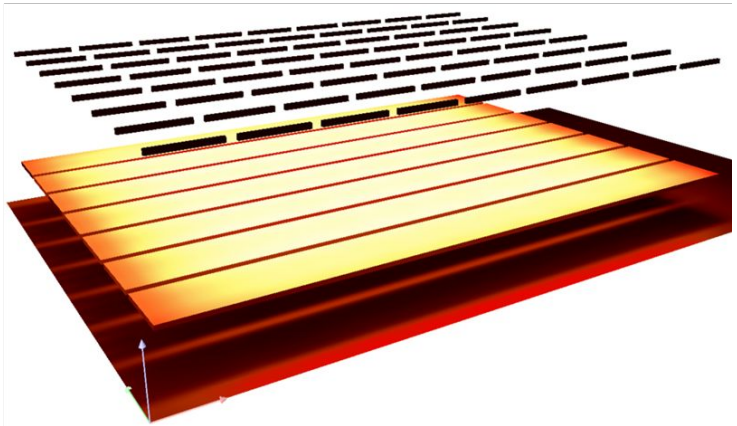
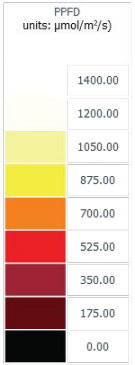


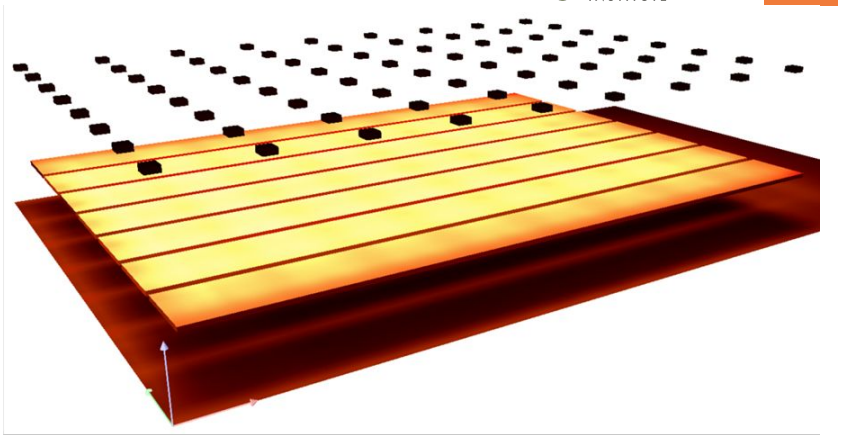
Figure credit: Fluence

HID ⇨ LED

WATTAGE MATCH

Metric	HPS	LED	Δ
Fixture Quantity	72 DE HPS 1000W	120 VYPR 2p	NA
Room PPF	126,000 µmol/s	204,000 µmol/s	+ 61.9%
PPFD Average	888 µmol/m²/s	1,453 µmol/m²/s	+63.62%
Total Electrical Input	75,600 watts	75,600 watts	Match
Lighting Power Density	67.5 w/ft²	67.5 w/ft²	Match
Fixture Mounting Height	3' from Canopy	3' from Canopy	NA
Canopy ft²	1,120 ft²	1,120 ft²	Match





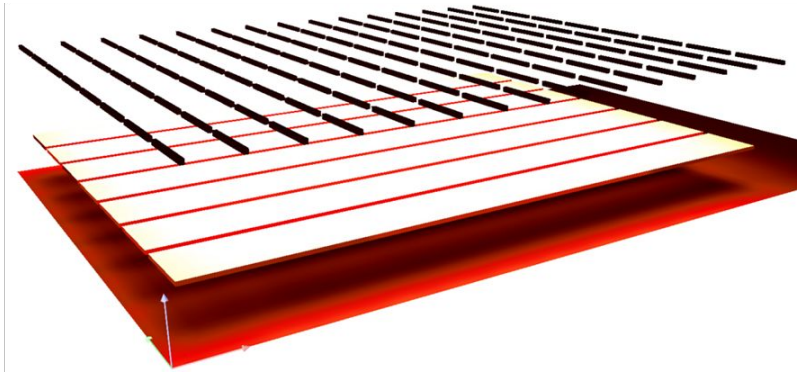


Figure credit: Fluence

HID ⇨ LED Multi-Tier Static 3 Tier

WATTAGE MATCH

Metric	HPS	LED	Δ
Fixture Quantity	72 DE HPS 1000W	150 SPYDR Series	NA
Room PPF	126,000 µmol/s	202,500 µmol/s	60.71%
PPFD Average	888 µmol/m²/s	844 µmol/m²/s	- 4.95
Total Electrical Input	75,600 watts	75,000 watts	- 0.79%
Lighting Power Density	67.5 w/ft²	31.25 w/ft2	- 53.7%
Fixture Mounting Height	3' from Canopy	12" from Canopy	NA
Canopy	1,120 ft²	2,400 ft²	114.28%

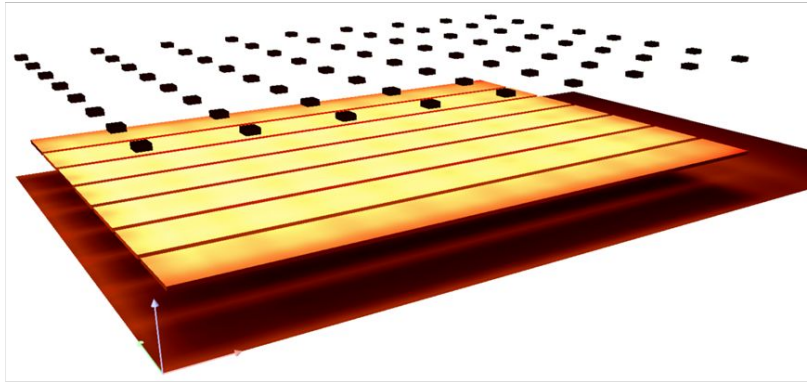
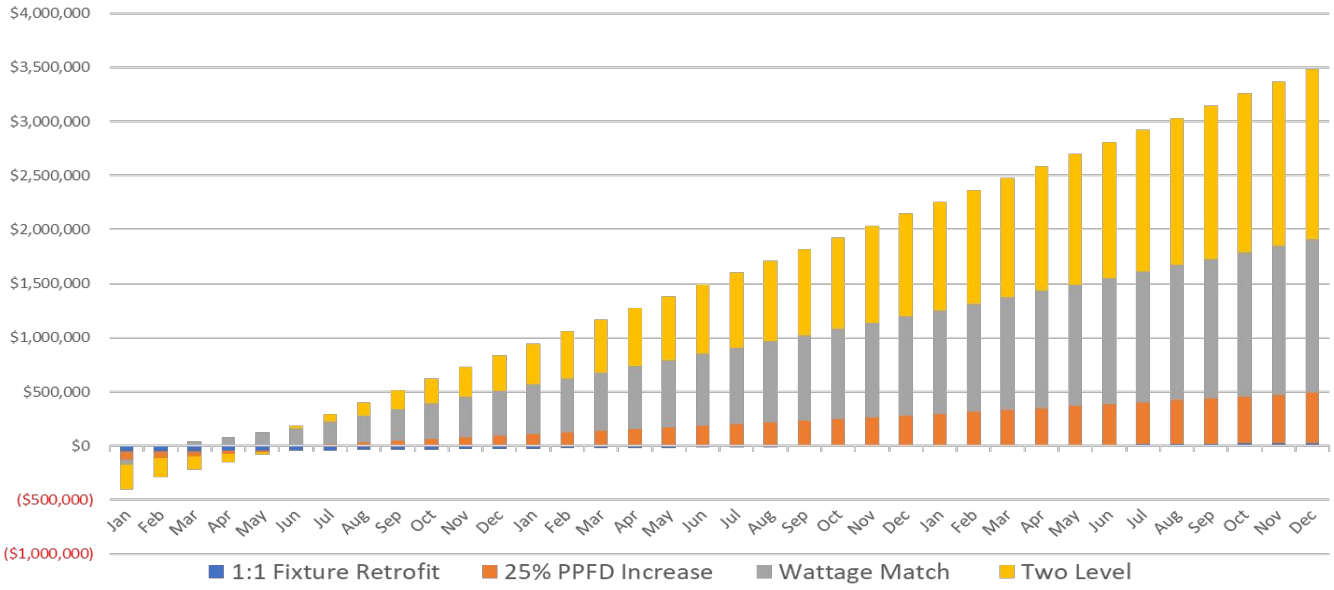


Figure credit: Fluence

THE FINANCIALS Simple Payback Year 3



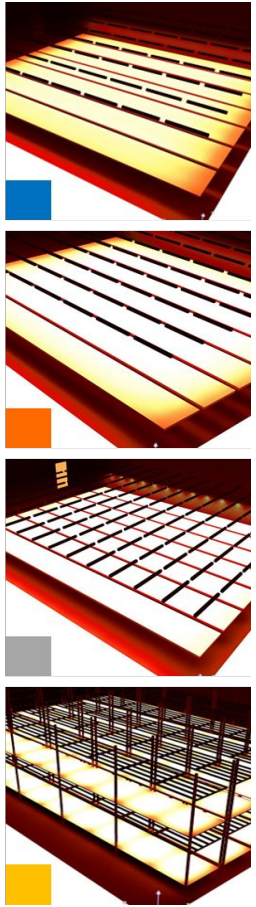


Figure credit: Fluence

SECTION 05

LED BEST PRACTICES FOR VERTICAL FARMS

Vertical Growing Considerations

Before you start

- Business model and financial plan
- Crop type and market needs
- Multi-level & size
- Equipment and micro-climates
- Mounting & wiring installation
- Zones and control
- Intensity and spectrum
- GMP, compliance, and incentives

Image credit: Fluence

LEDs for Vertical Growing

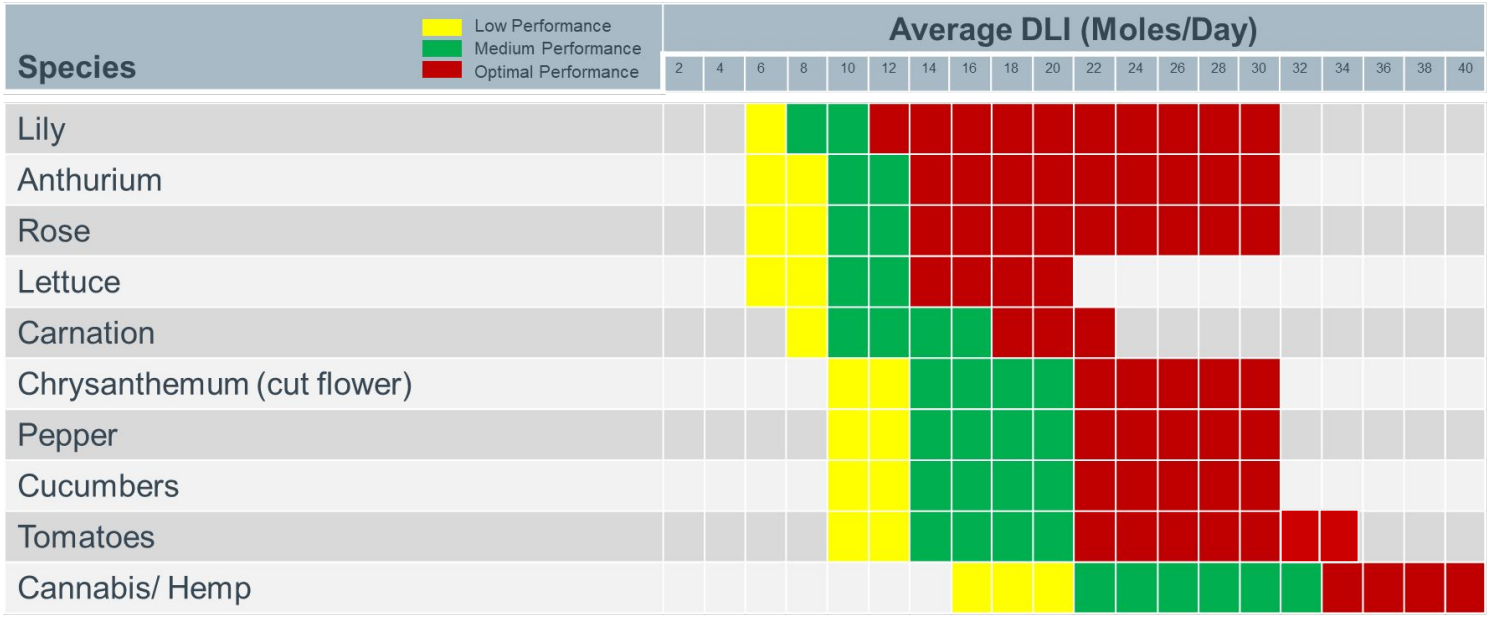
Application Specific

- Crop Type
- Above vs. Intracanopy
- Propagation/ Seedlings
- Vegetative
- Flowering/ Fruiting

Image credit: Fluence

Planning for Stages of Growth

What is being grown, what does it need?



- These values are sourced from James E. Faust, Ball Red Book, as well as independent research.

Figure credit: Fluence

Crop Steering : Photo Acclimation

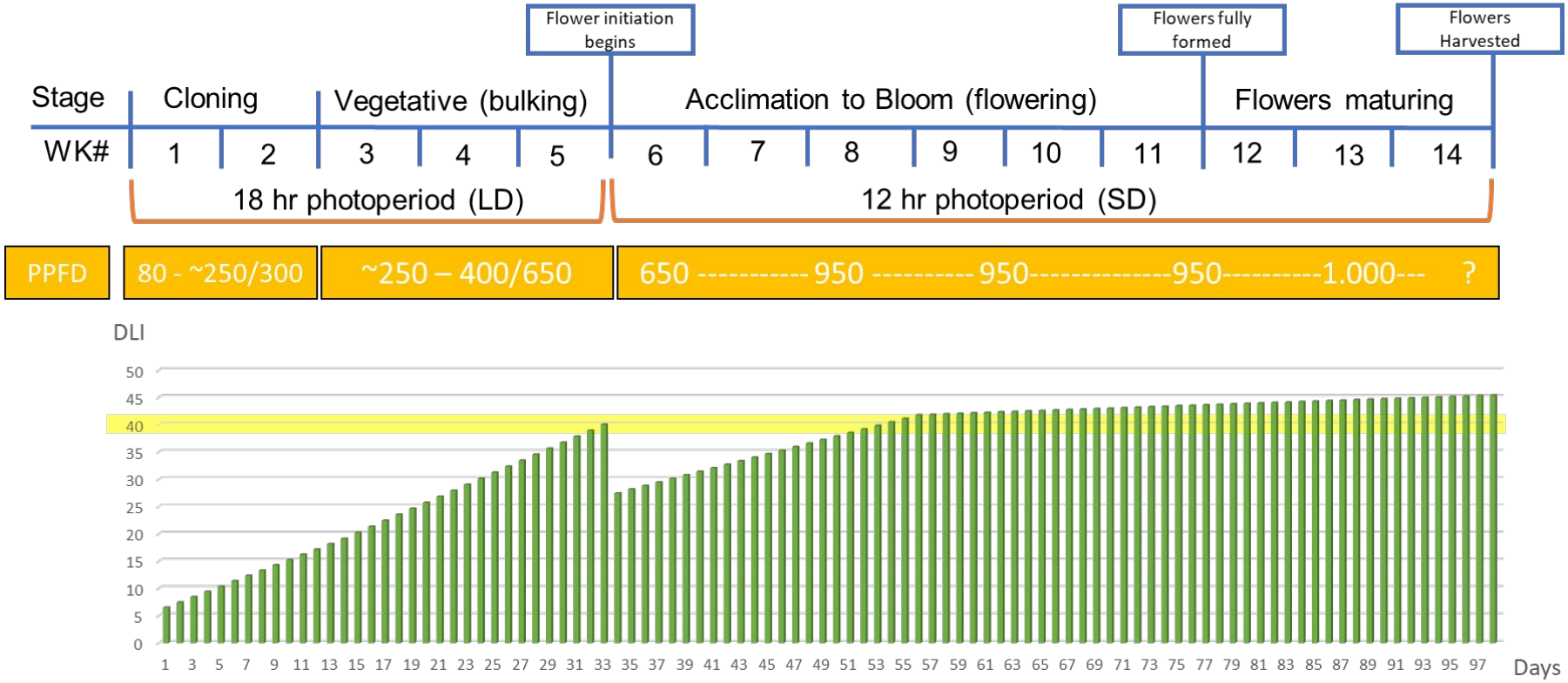


Figure credit: Fluence

Choose Spectra for Crop Applications

SQD Optimized for Growth Stages

- Crop Type
- Facility Type
- Broad/ Narrow
- Custom Spectrum
- Intensity
- Efficacy

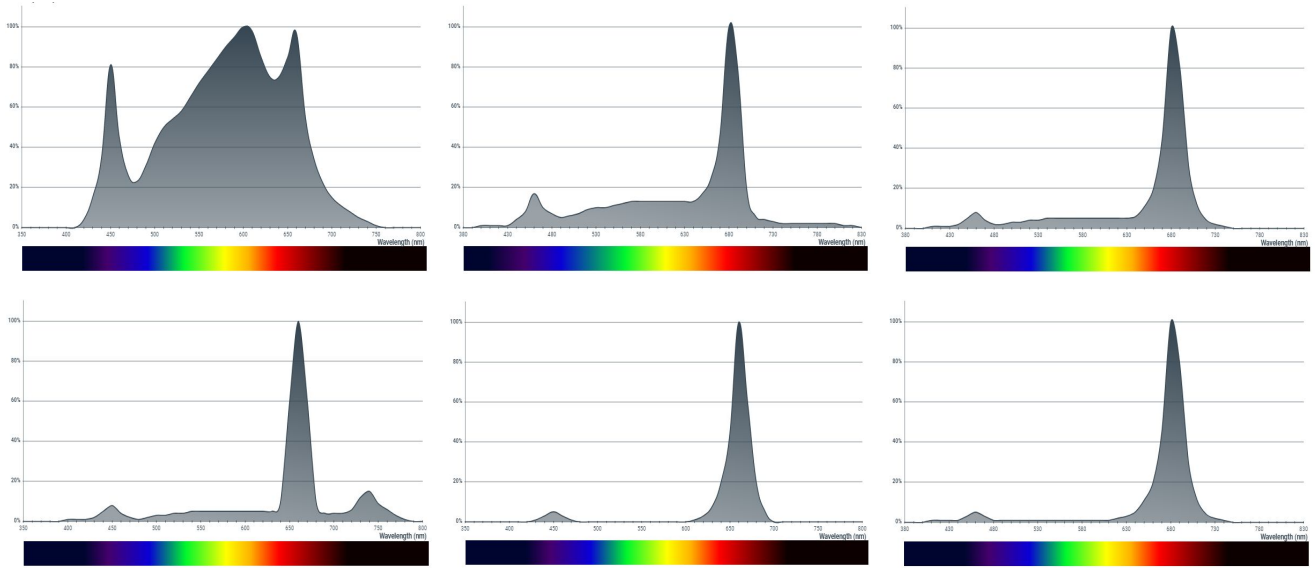


Image credit: Fluence

SECTION 07

CONSIDERATIONS FOR LIGHTING CONTROLS

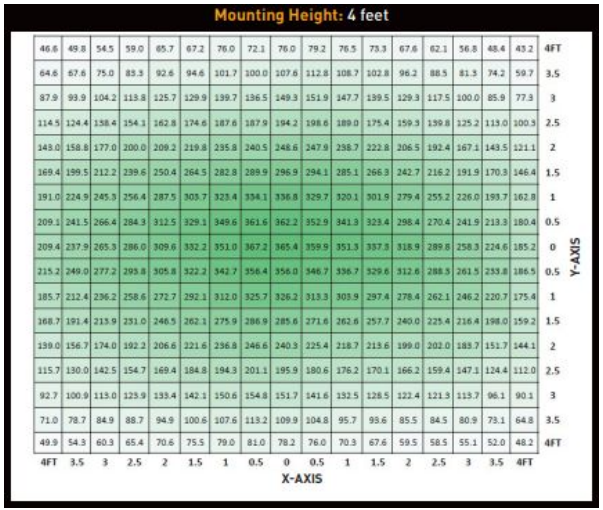
Importance of Lighting Control

Lighting

- #1 growth input for plants
- Plant development, genetics, fertigation, and environment conditions
- Amount and quality

Control Systems

- Adjusting intensity and tuning spectra
- Managing lighting schedules
- Monitoring canopy conditions
- Automatic response



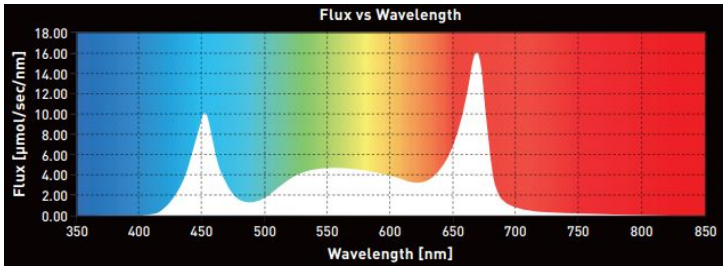


Image credit: Hawthorne

Planning Lighting Controls

Key Considerations

- Facility type and location
- New construction or existing
- Lighting
- Crop being grown
- Zones of control
- Wireless vs wired
- Key points to monitor
- Systems to control vs systems to monitor
- Balancing efficiency
- Cost vs. performance
- Response rates
- Maximizing production
- Perpetual harvest

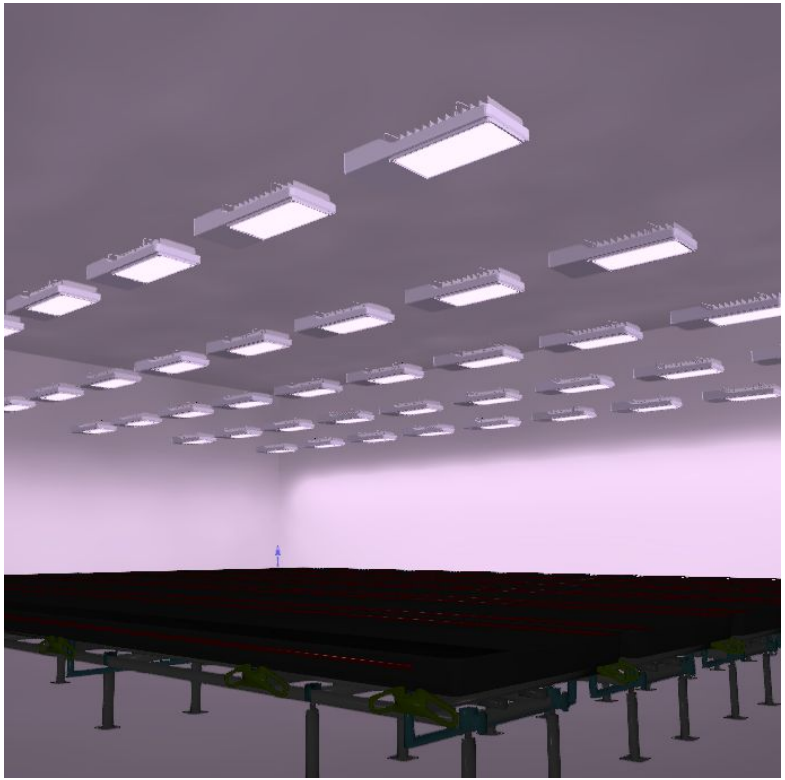


Image credit: DIALux Evo, Hawthorne

Lighting Controls Strategies

Scheduling

- Adjust photoperiod

Dimming

- Modulate lighting intensity
  - Daily
  - By stage of plant growth

Spectral Tuning

- Modulate photon output from wavelength ranges

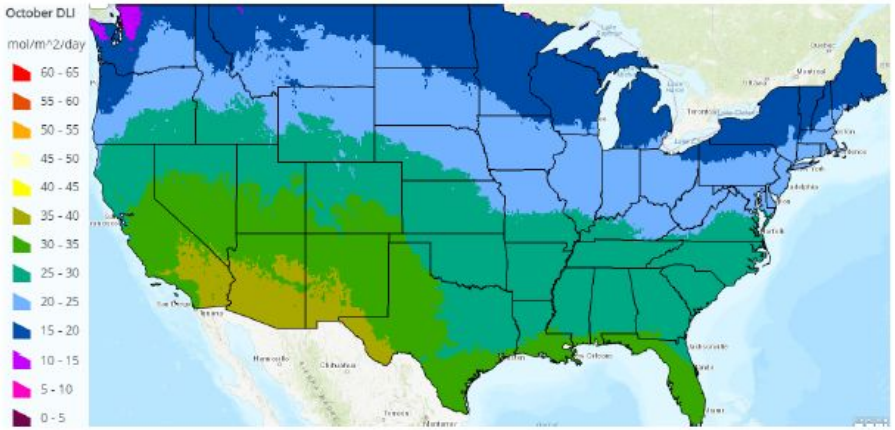


Table 2: Lighting Schedules and DLI Targets for Cannabis Cultivation

Cannabis Growth Stage	Average DLI Target for Cannabis (Moles/Square Meter/Day)	Example Sole-Source Daily Lighting Hours (Indoor)	Example Supplemental Daily Lighting Hours[3] (Greenhouse)
Flower/Bloom	25 - 50	12	North: 6 - 8 hours South: 5 - 6 hours
Vegetative	20 - 40	18 - 24[4]	North: 4 - 6 hours South: 1 - 3 hours
Clone/Seedling	15 - 20	14 - 24	North: 0 - 2 hours South: Not needed
Mother	20 - 40	18	North: 4 - 6 hours South: 1 - 3 hours

Image credit: American Floral Endowment, RII Cannabis Controls Best Practices Guide, Hawthorne

Data Collecting for Cannabis Steering

Gather data to validate performance, support lighting controls incentives, and understand energy savings

Table 3: Lighting Controls Parameters Measured by Cannabis Cultivators

Lighting Data Collected[5]	Percentage of Growers Collecting, 2020
Light intensity (PPFD)	55%
Spectral quality	33%

Table 4: Lighting Controls for Cannabis Steering by Stage of Plant Growth[6]

Lighting Controls	Vegetative	Flowering	Ranges of Controls Values
PPFD	Lower	Higher	300 - 1500+ µmols/m²/s
DLI	Less	More	20 - 42 moles/m²/day
Spectral Treatments (R:B ratio)	Higher	Lower	7 - 15%; higher blue for shorter plants
Far Red Treatments	More	Less	Used to manage shade avoidance

Figure credit: RII Cannabis Controls Best Practices Guide

SECTION 08

COMMISSIONING LIGHTING CONTROLS

Lighting Controls Equipment

- Quantum sensors
- Data loggers
- Dimming Controllers
- Building Management Systems

Image credit: Hawthorne

Configure Control Equipment

Sensors

- Type and setup
- Maintenance

Controllers

- Type
- Compatibility and connectivity
- Programmability
- Data logging

Targets

- Zones
- Set point values and ranges
- Automation
- Energy usage

Image credit: RII Cannabis Controls Best Practices Guide, Hawthorne

Control Sequence

Verify
Validate
Monitor

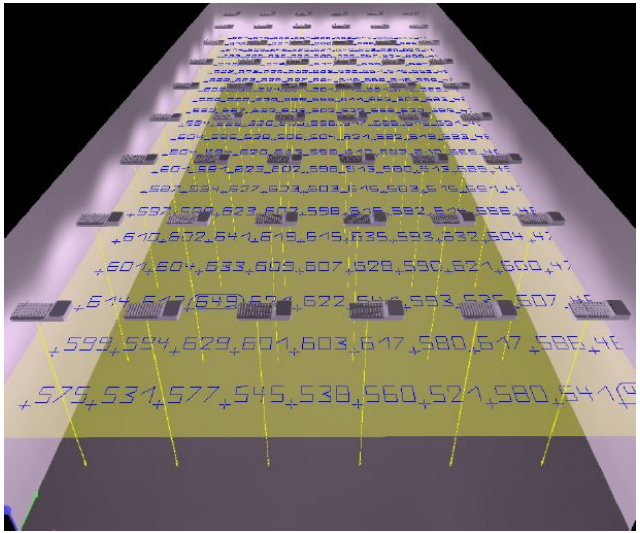


Image credit: RII Cannabis Controls Best Practices Guide, DIALux Evo, Hawthorne

SECTION 08

BENCHMARKING LIGHTING PERFORMANCE

Document Baselines

Capture Market Practices and Performance

Benchmark your production environments to create baselines for resource efficiency:

- Energy
- Water
- Emissions

Understand how your facility performs compared to your key performance targets

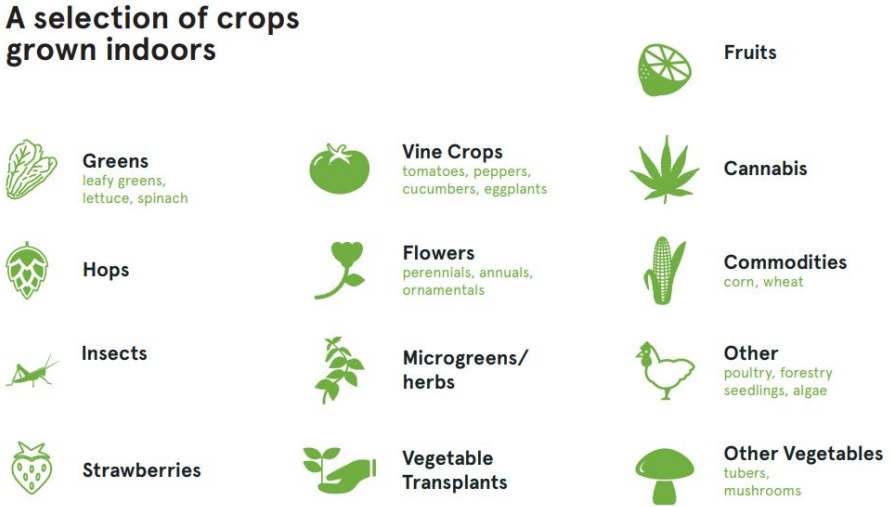


Figure credit: Rhode Island Department of Environmental Management

Facility Performance Snapshots

Key Performance Indicators for CEA

Quantify performance of CEA facilities using specialized key performance indicators for:

- Efficiency
- Productivity

Understand how lighting system operation affects facility lighting and energy KPIs

- Efficiency : W / day / sq ft
- Productivity : W / day / lb

Observe changes in canopy productivity

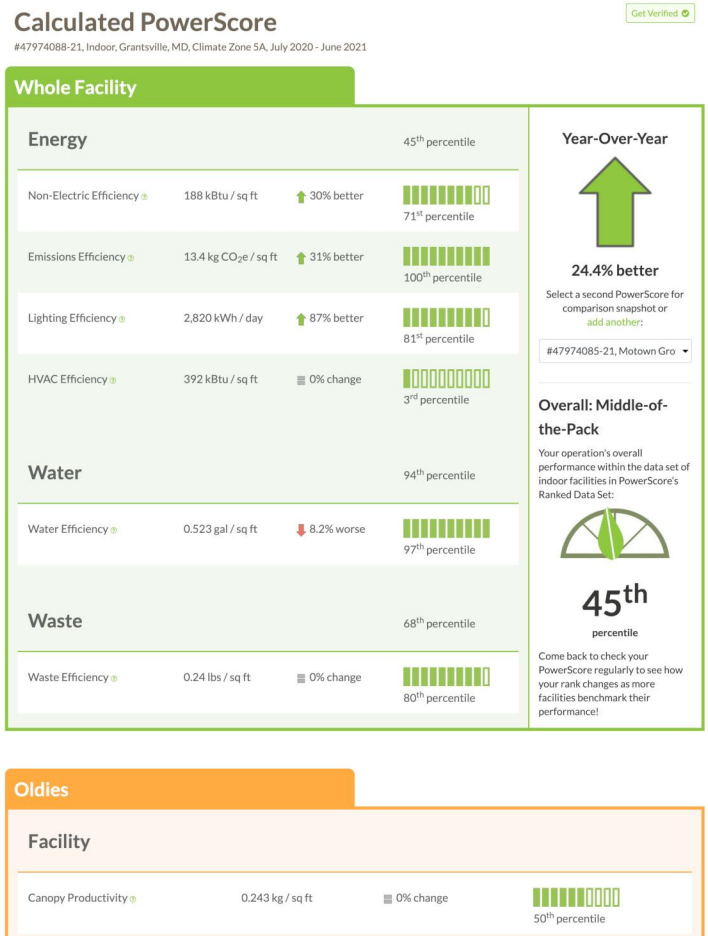


Figure credit: RII, PowerScore

SECTION 09

SCE NEW LIGHTING INCENTIVES

Get in Touch with Our Sponsor

Program Offerings

- On bill financing
- GoGreen business energy financing
- Vendor partner rebates and incentives
- New programs in development!
- Summer Reliability Program (SRP)
  - performance-based compensation to reduce energy usage during times of high grid stress
  - sce.com/srp

Connect:

SummerReliabilityProgram@sce.com

SOUTHERN CALIFORNIA EDISON

Summer Reliability Program

Offers Trade Professionals performance-based compensation to reduce energy usage during times of high grid stress with the goal to avoid rotating outages while minimizing costs to ratepayers.

- Budget: $60M
- Program Materials and to enroll as a Trade Professional
- streamlined application and review process that will allow projects to be approved and installed within a reduced timeframe
- Pre- and post- site audits are also not required
- Trade Professionals will be compensated over three 4-month periods using a performance-based Population Normalized Metered Energy Consumption methodology
- Performance is tied to grid benefits based on the hourly avoided cost value of projects
- LED lighting fixtures are required to be DLC listed. Energy savings will be compared against the existing baseline.

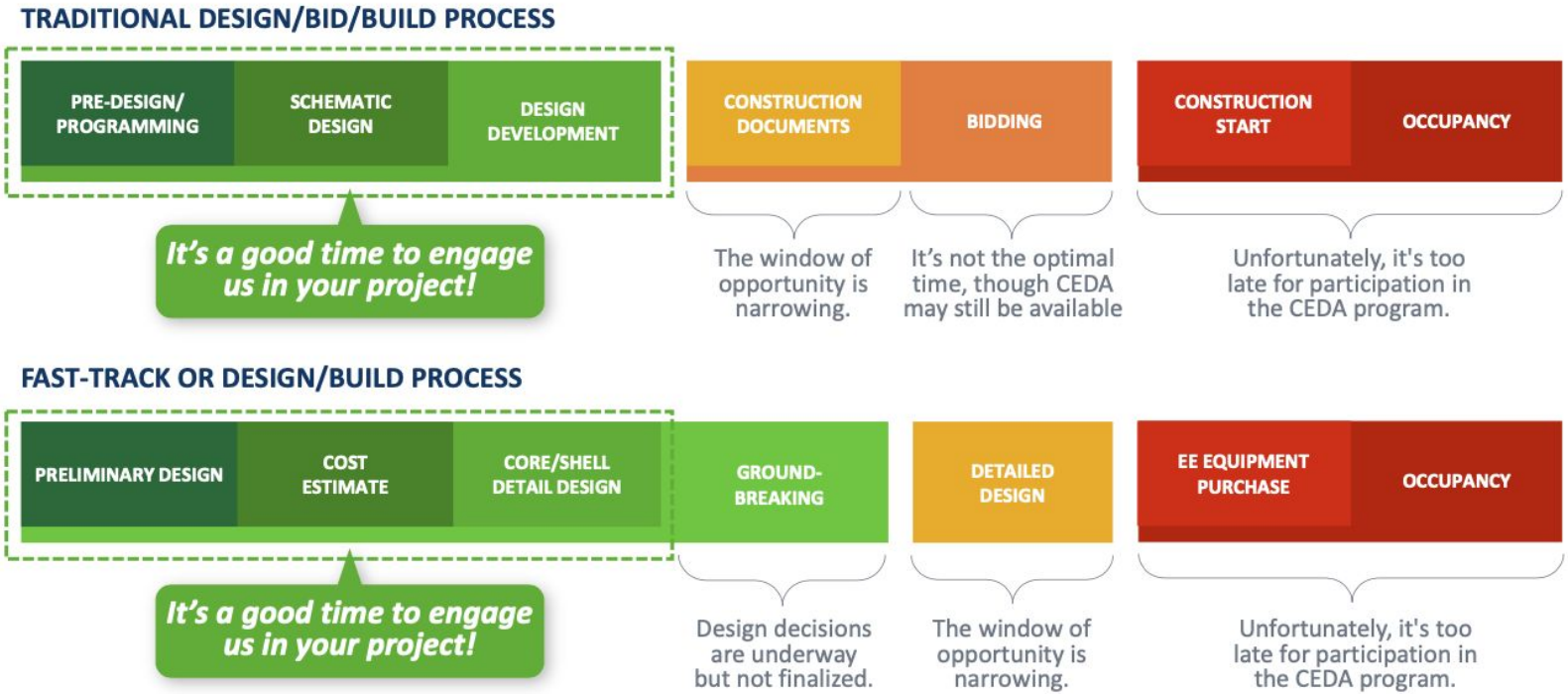
Statewide CEDA Program for Producers

California Energy Design Assistance (CEDA)
New Construction Program

Visit CaliforniaEDA.com

- Statewide Program serving PG&E, SCE, SoCal Gas, SDGE
  - Program participants receive the following complimentary services:
    - Comprehensive Whole Building Energy Analysis
    - Assistance identifying and evaluating energy-saving measures
    - Analysis of energy costs and paybacks
    - Incentives for New Construction and Major Renovations projects
  - CEDA Pathways: Mixed Fuels or All-Electric
    - Mixed Fuels for customers who want the option of both gas and electricity
    - All-Electric program option offers higher incentives if customers do not install gas service

Statewide CEDA Program for Producers




Q&A

CONTACT US

RESOURCE INNOVATION INSTITUTE

Visit us at
www.ResourceInnovation.org

P.O. Box 5981
Portland, Oregon 97228
derek@resourceinnovation.org
gretchen@resourceinnovation.org
carmen@resourceinnovation.org