Horticultural Lighting Science

And SSL Technology

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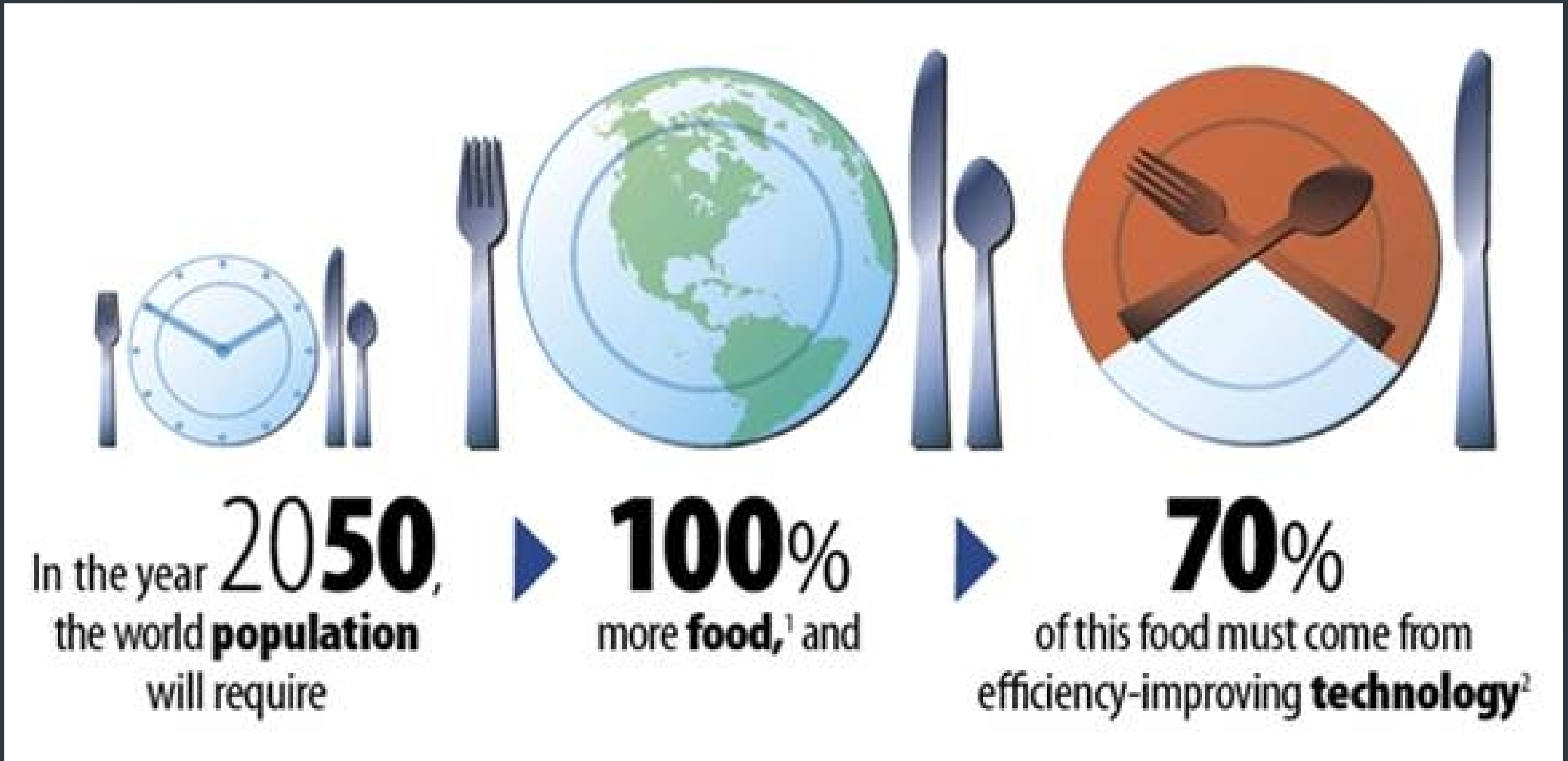
Co-Founder & CEO, Fluence Bioengineering

Agenda

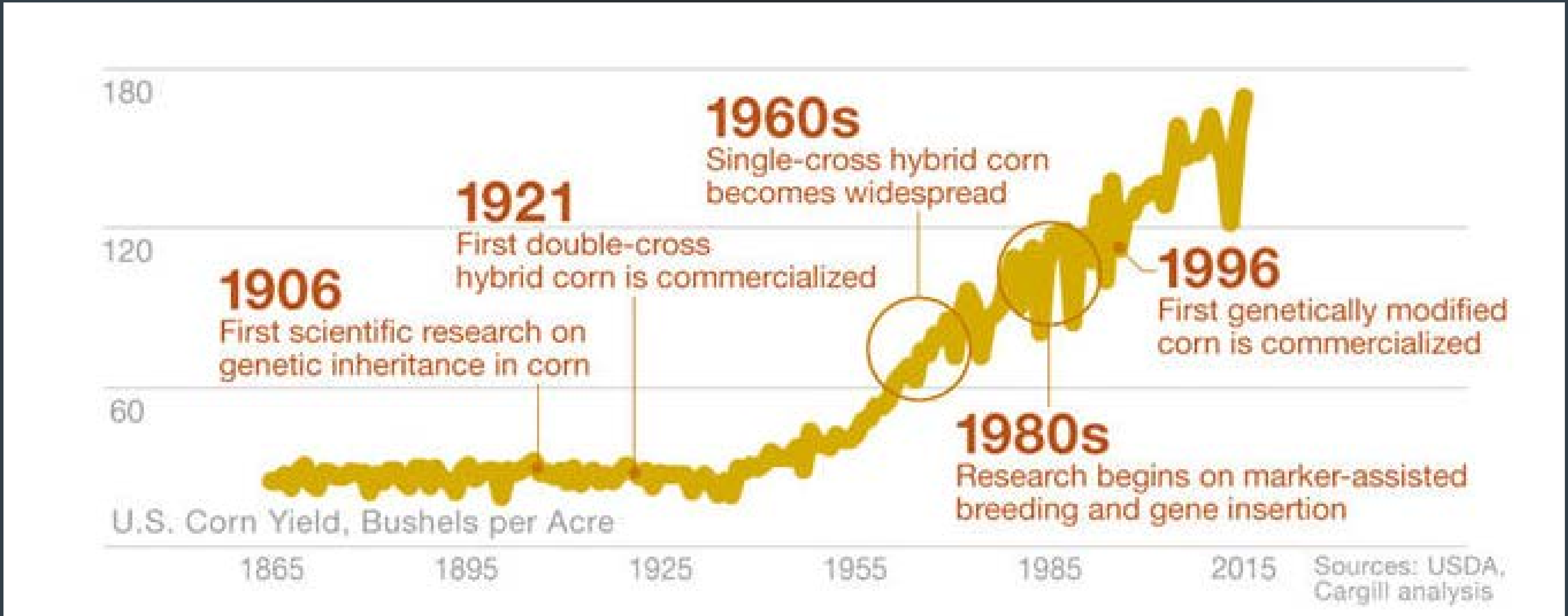
- Why Horticulture Lighting?
- Horticulture Lighting vs. General Lighting
- Photobiology Overview
- Lighting Fixture Considerations

Why Horticulture Lighting?

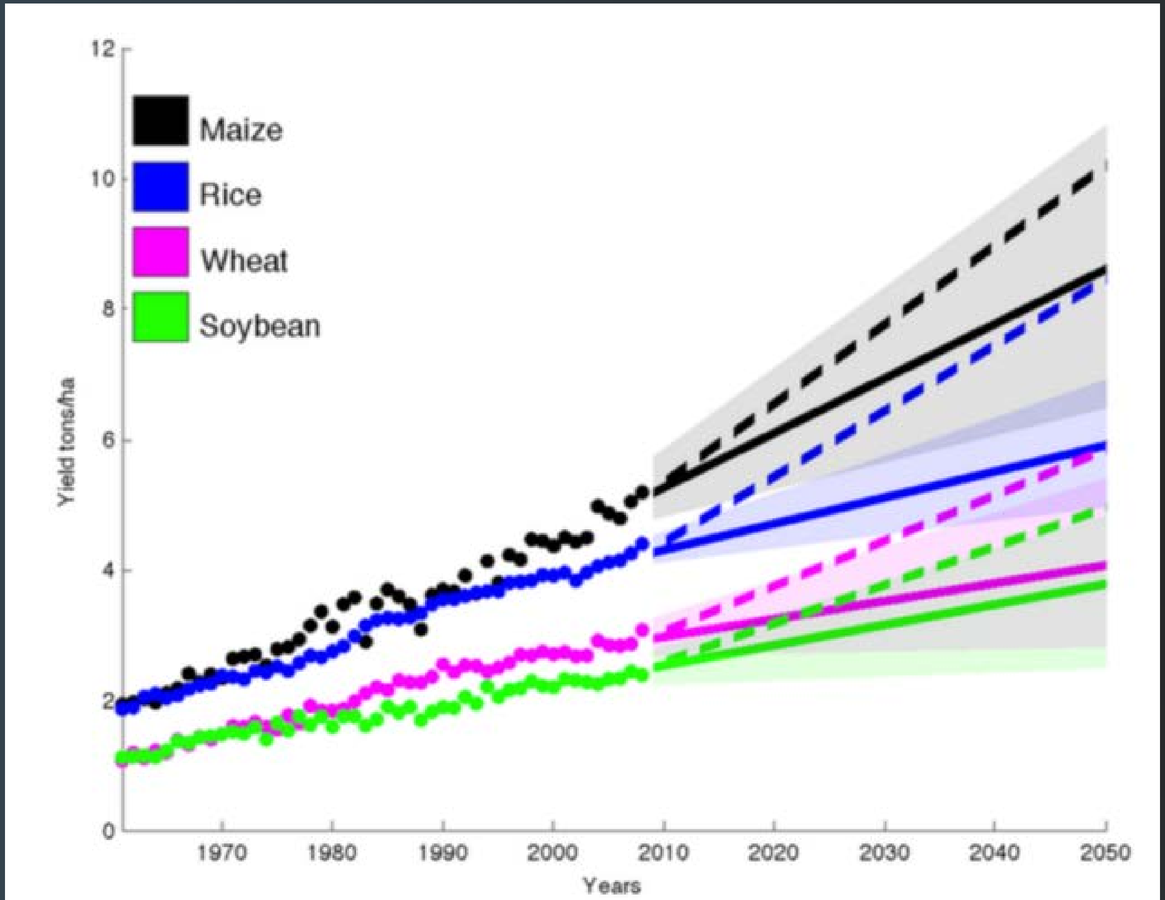
Food and Agriculture Organization of the United Nations



U.S. CORN YIELDS: A HISTORY OF INNOVATION



Agriculture efficiency is not improving fast enough to feed the growing population



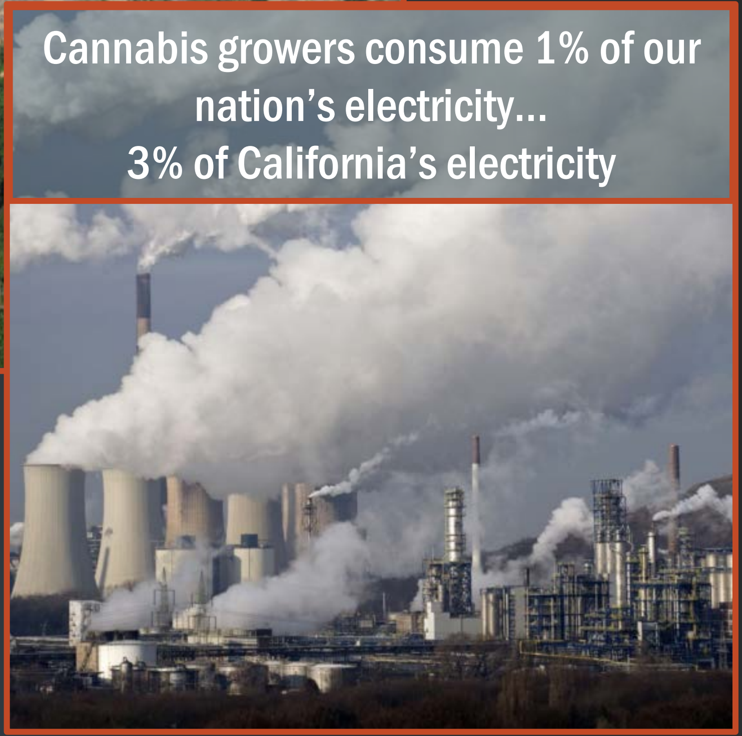
Required Crop Production Efficiency Gain per Year:

2.4%

Actual Crop Production Efficiency Gain per Year:

1.6%


The equivalent of 36 football fields of forests are cleared every minute


Cannabis growers consume 1% of our nation’s electricity…
3% of California’s electricity


The recent drought in California led to 524,000 fallowed acres, which cost the state $1.84B in 2015

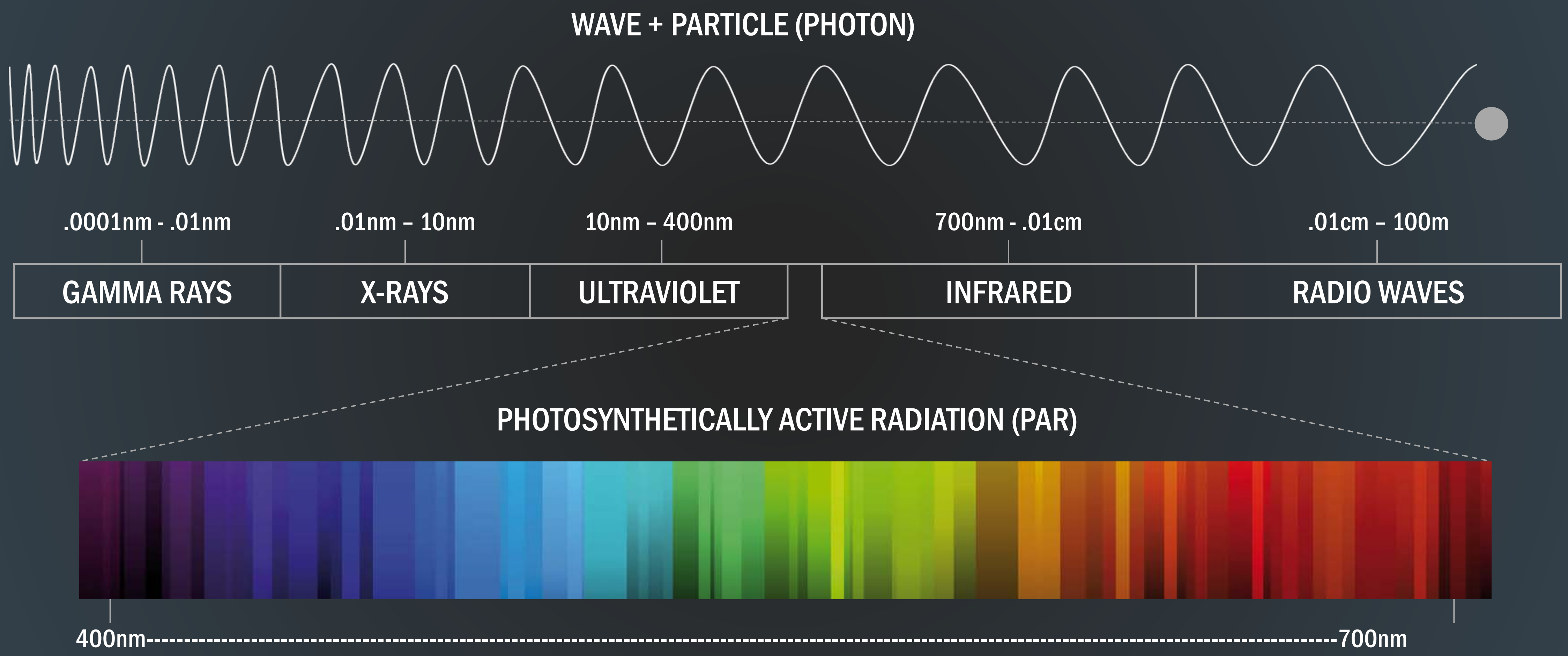
Solution ?

Controlled Environment Agriculture (CEA)

Indoor Farming and High-Tech Greenhouses

Horticulture Lighting vs. General Lighting

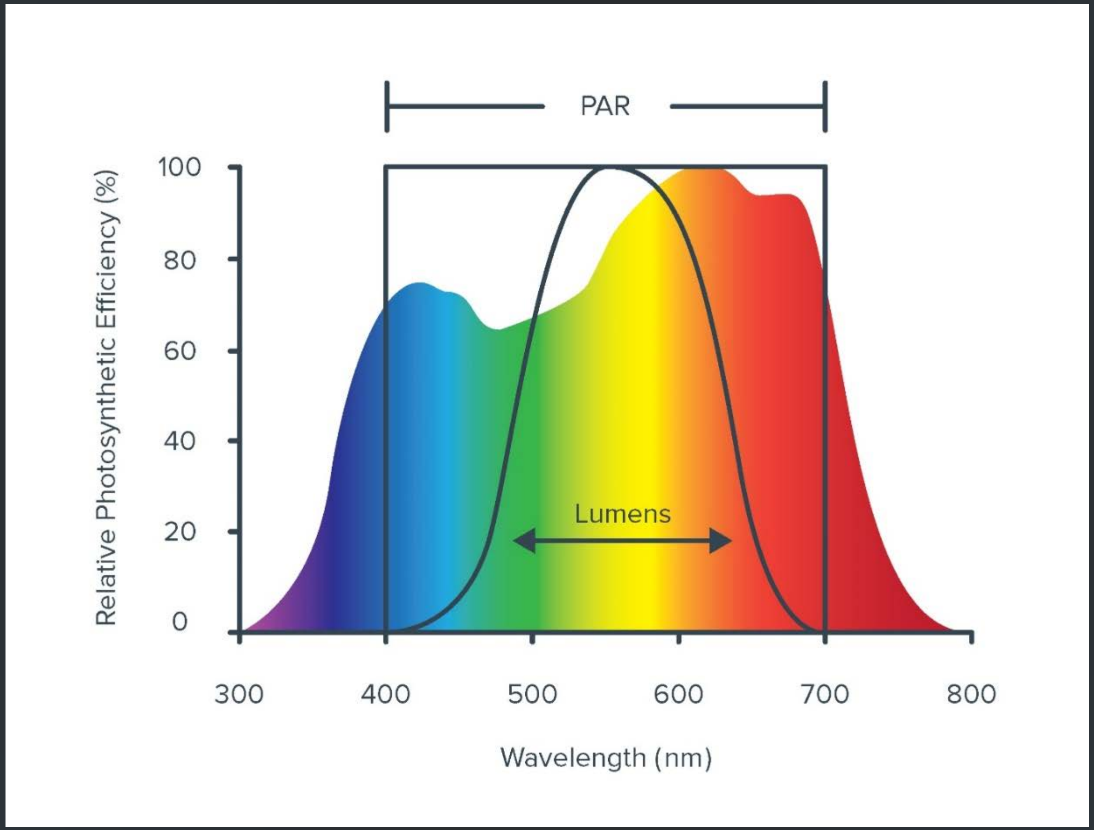
Electromagnetic Radiation Spectrum



METRICS
VISION vs. HORTICULTURE

Photopic Vision

- Lumens
- Lux / Foot-Candles
- Lumens / Watt



Horticulture

- PPF
- PPFD
- μmol / J

GENERAL LIGHTING vs. HORTICULTURE LIGHTING

Typical Lighting Power Density (LPD)

- Office Space: 1 W/ft^2
- Lettuce Vertical Farm: 10 W/ft^2
- Tomato Greenhouse: 15 W/ft^2
- Cannabis Greenhouse: 30 W/ft^2
- Cannabis Indoor: 65 W/ft^2

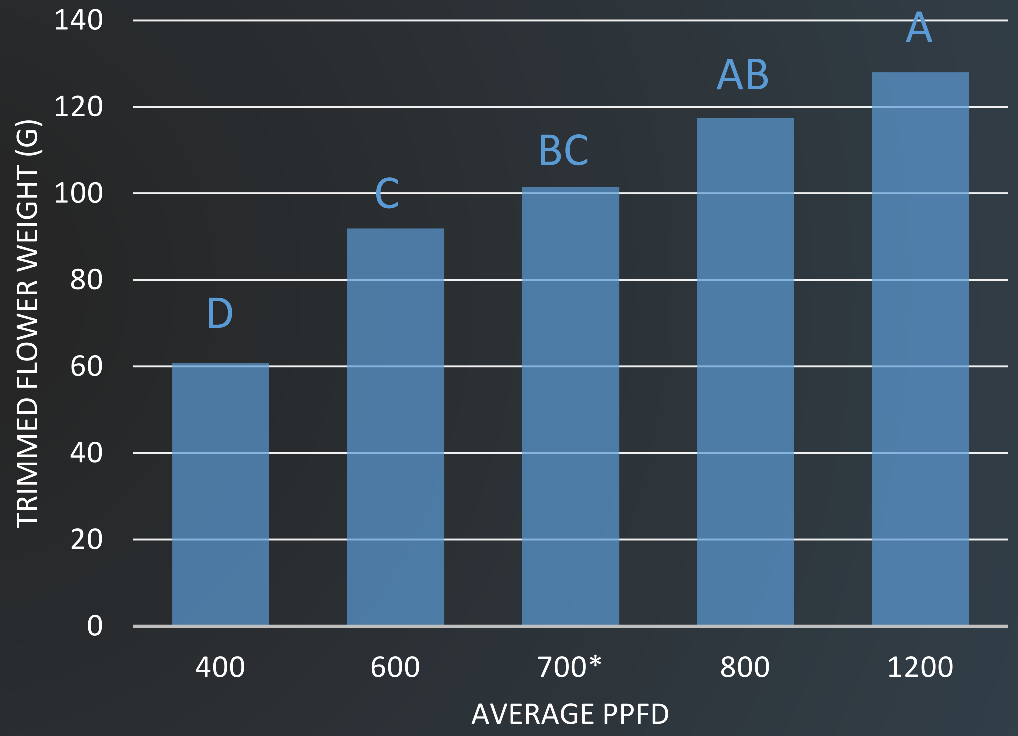
Photobiology Overview

PHOTOBIOLOGY – 3 PILLARS

PHOTOSYNTHESIS

SERIES OF LIGHT & DARK REACTIONS THAT OCCURS IN THE CHLOROPLASTS USING LIGHT ENERGY (PHOTOSYNTHETIC PHOTON FLUX) TO GENERATE CARBOHYDRATES FROM CO2 AND H20.

YIELD

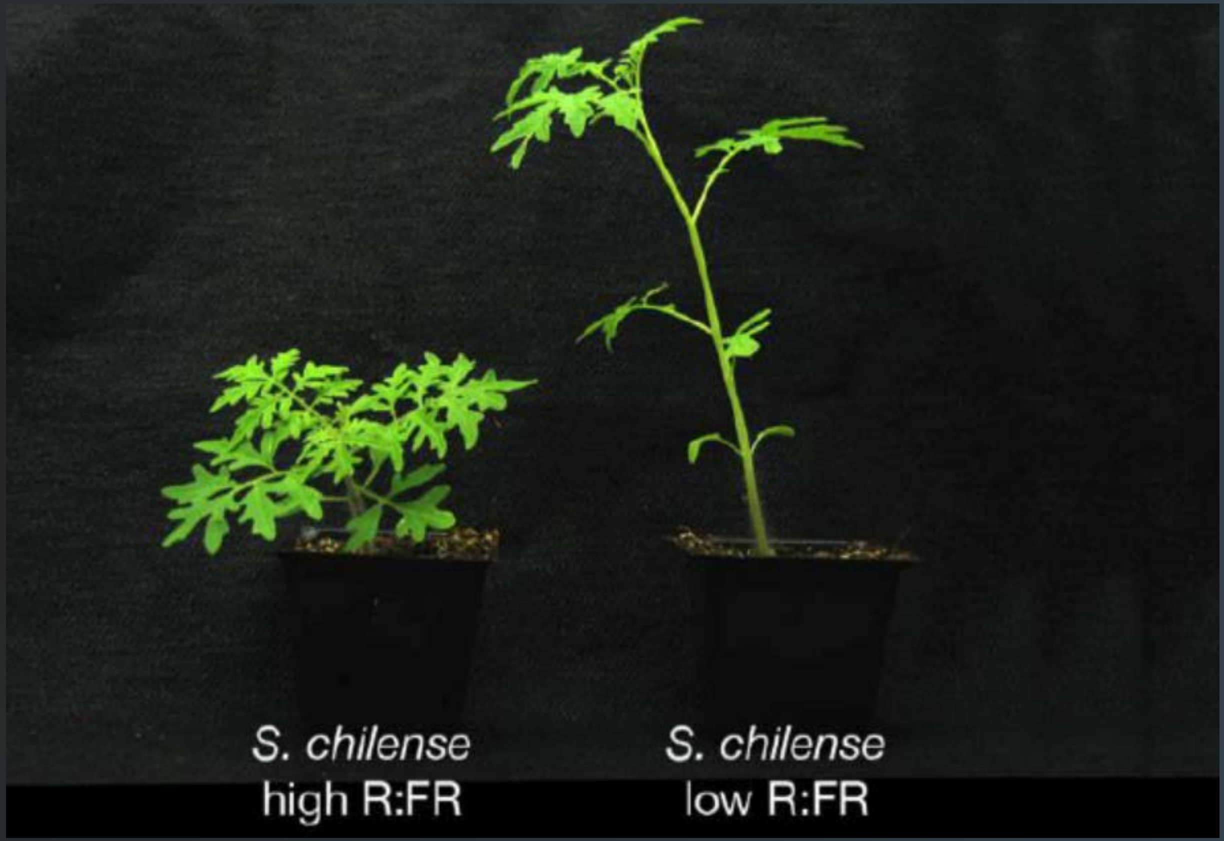


PHOTOBIOLOGY – 3 PILLARS

PHOTOMORPHOGENESIS

LIGHT-CONTROLLED PROCESSES THAT REGULATE PLANT PHYSIOLOGICAL DEVELOPMENT OF FORM AND STRUCTURE

QUALITY

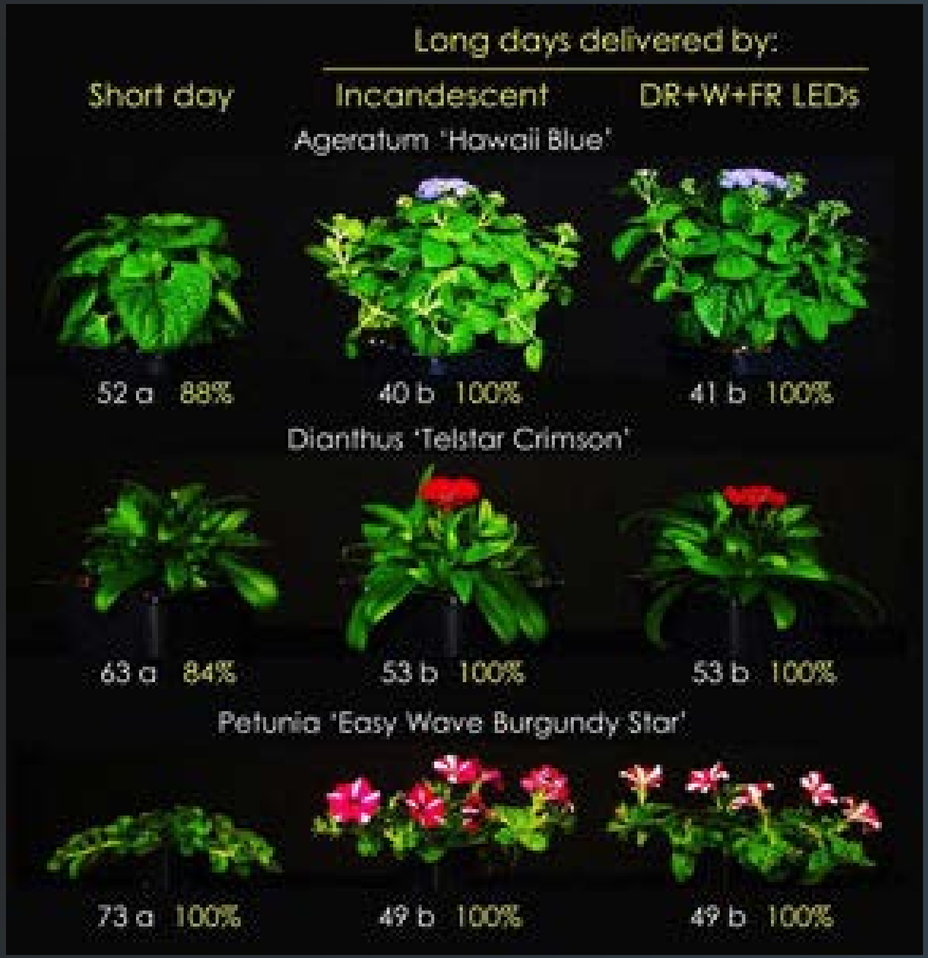


PHOTOBIOLOGY – 3 PILLARS

PHOTOPERIODISM

PHYSIOLOGICAL RESPONSE TO RELATIVE LENGTHS OF LIGHT AND DARK PERIODS

FLOWER/FRUIT MANIPULATION



Lighting Fixture Considerations

HORTICULTURE LIGHTING

Fixture requirements in commercial agriculture

PPF | PPFD | UNIFORMITY | SPECTRUM | EFFICACY | SIZE | PROXIMITY

The amount of photosynthetically active light emitted by a fixture.

Micromoles per second (µmol/s) 400-700nm

HORTICULTURE LIGHTING

Fixture requirements in commercial agriculture

PPF | **PPFD** | UNIFORMITY | SPECTRUM | EFFICACY | SIZE | PROXIMITY

The amount of light reaching your canopy.

Micromoles per meter squared per second (µmol/m^2/s) 400-700nm

TYPICAL PPFD REQUIREMENTS

Lighting Application	PPFD ($\mu mol/m^2/s$)	Foot-candle ($lumen/ft^2$)	LUX ($lumen/m^2$)
Office Space	6 - 10	30 - 50	324 - 540
Lettuce	200 - 300	1002 - 1503	10,800 - 16,200
Herbs	300 - 500	1503 - 2505	16,200 - 27,000
Tomatoes	500 - 700	2505 - 3507	27,000 - 37,800
Cannabis	700 - 900	3507 - 4509	37,800 - 48,600

* Conversion factors based on the spectrum of sunlight

HORTICULTURE LIGHTING

Fixture requirements in commercial agriculture

PPF | PPFD | **UNIFORMITY** | SPECTRUM | EFFICACY | SIZE | PROXIMITY

The average, maximum and minimum amount of PPFD.

HORTICULTURE LIGHTING

Fixture requirements in commercial agriculture

PPF | PPFD | UNIFORMITY | **SPECTRUM** | EFFICACY | SIZE | PROXIMITY

The proportions of different wavelengths


SPECTRAL POWER DISTRIBUTION CHART
High Pressure Sodium
FLUENCE
BIOENGINEERING
Measurements of Normalized
Photosynthetic Photon Flux
100%
80%
60%
40%
20%
0
360
430
480
530
580
630
680
730
780
Wavelength
nm


SPECTRAL POWER DISTRIBUTION CHART
PhysioSpec Indoor™
FLUENCE
BIOENGINEERING
Measurements of Normalized
Photosynthetic Photon Flux
100%
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730
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Wavelength
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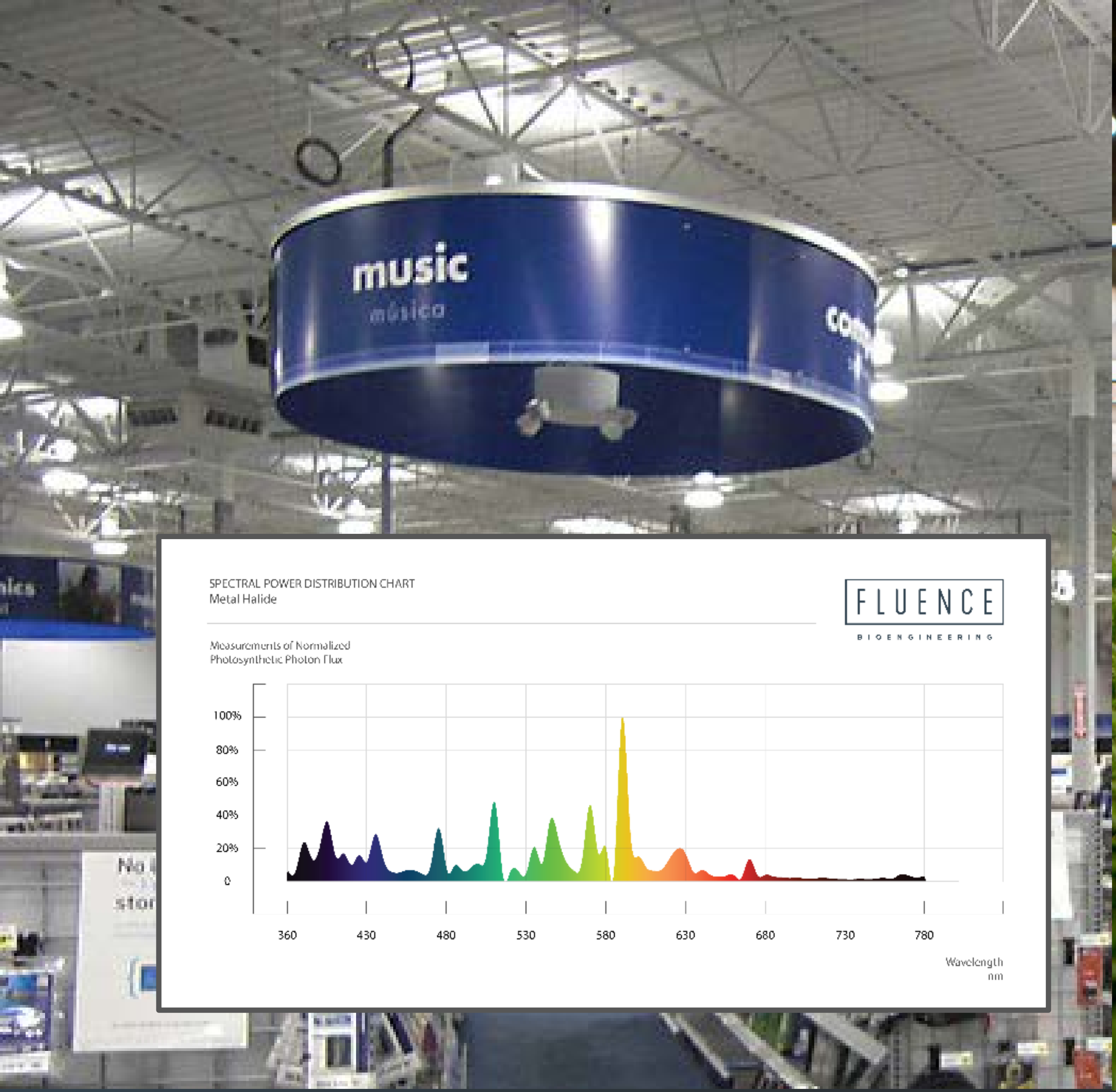
music
música
SPECTRAL POWER DISTRIBUTION CHART
Metal Halide
FLUENCE
BIOENGINEERING
Measurements of Normalized
Photosynthetic Photon Flux
100%
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Wavelength
nm


SPECTRAL POWER DISTRIBUTION CHART
PhysioSpec Greenhouse™
FLUENCE
BIOENGINEERING
Measurements of Normalized
Photosynthetic Photon Flux
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Wavelength
nm


SPECTRAL POWER DISTRIBUTION CHART
T5 Fluorescent
FLUENCE
BIOENGINEERING
Measurements of Normalized
Photosynthetic Photon Flux
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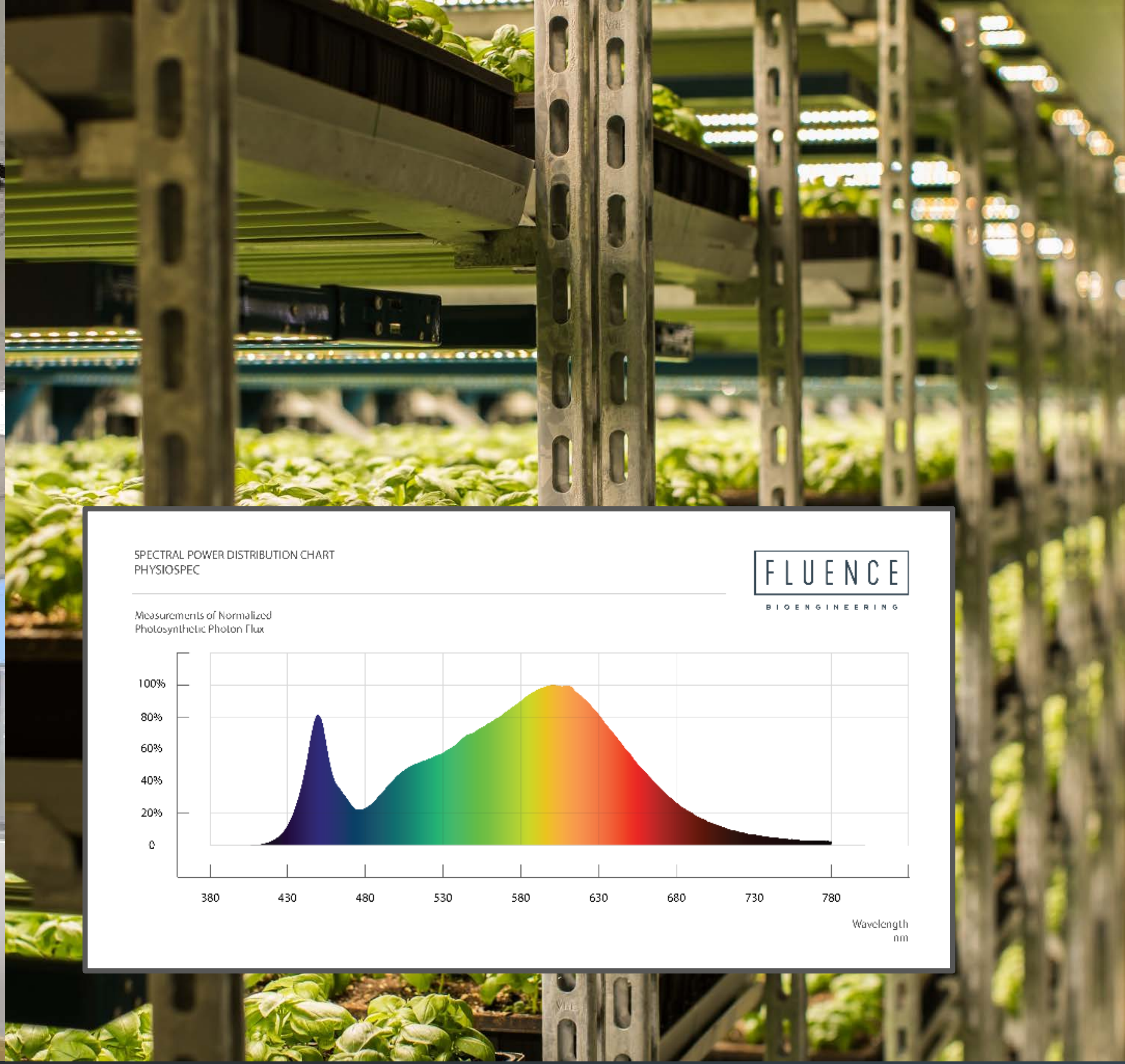
SPECTRAL POWER DISTRIBUTION CHART
PHYSIOSPEC
FLUENCE
BIOENGINEERING
Measurements of Normalized
Photosynthetic Photon Flux
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SPECTRAL POWER DISTRIBUTION CHART
AnthoSpec™
FLUENCE
BIOENGINEERING
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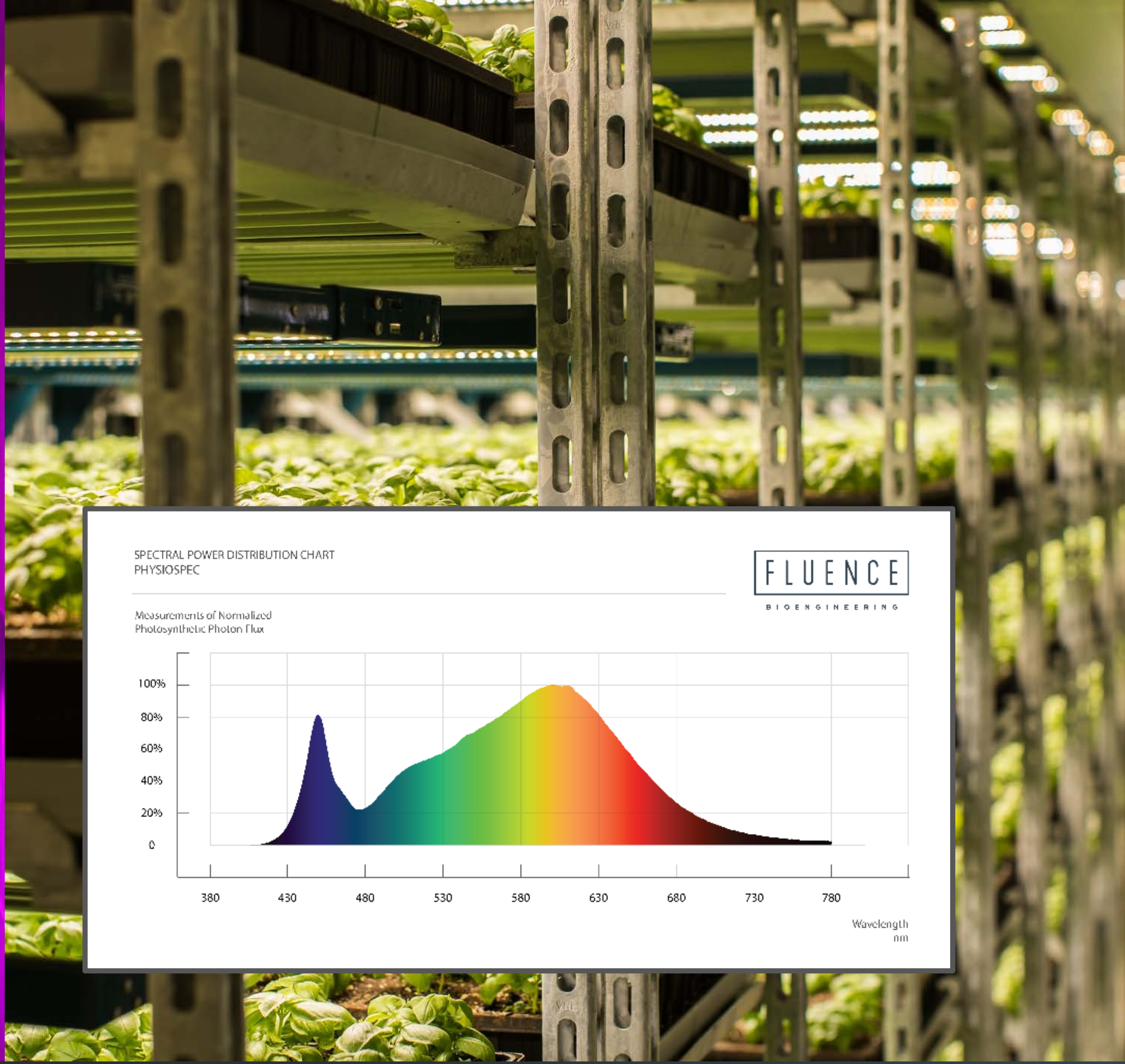
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Wavelength
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SPECTRUM

HORTICULTURE LIGHTING

Fixture requirements in commercial agriculture

PPF | PPFD | UNIFORMITY | SPECTRUM | EFFICACY | SIZE | PROXIMITY

Fixture efficiency of converting electrons into photons.

Micromoles per joule (µmol/J)


SPECTRAL POWER DISTRIBUTION CHART
AnthoSpec ™
FLUENCE
BIOENGINEERING
Measurements of Normalized
Photosynthetic Photon Flux
100%
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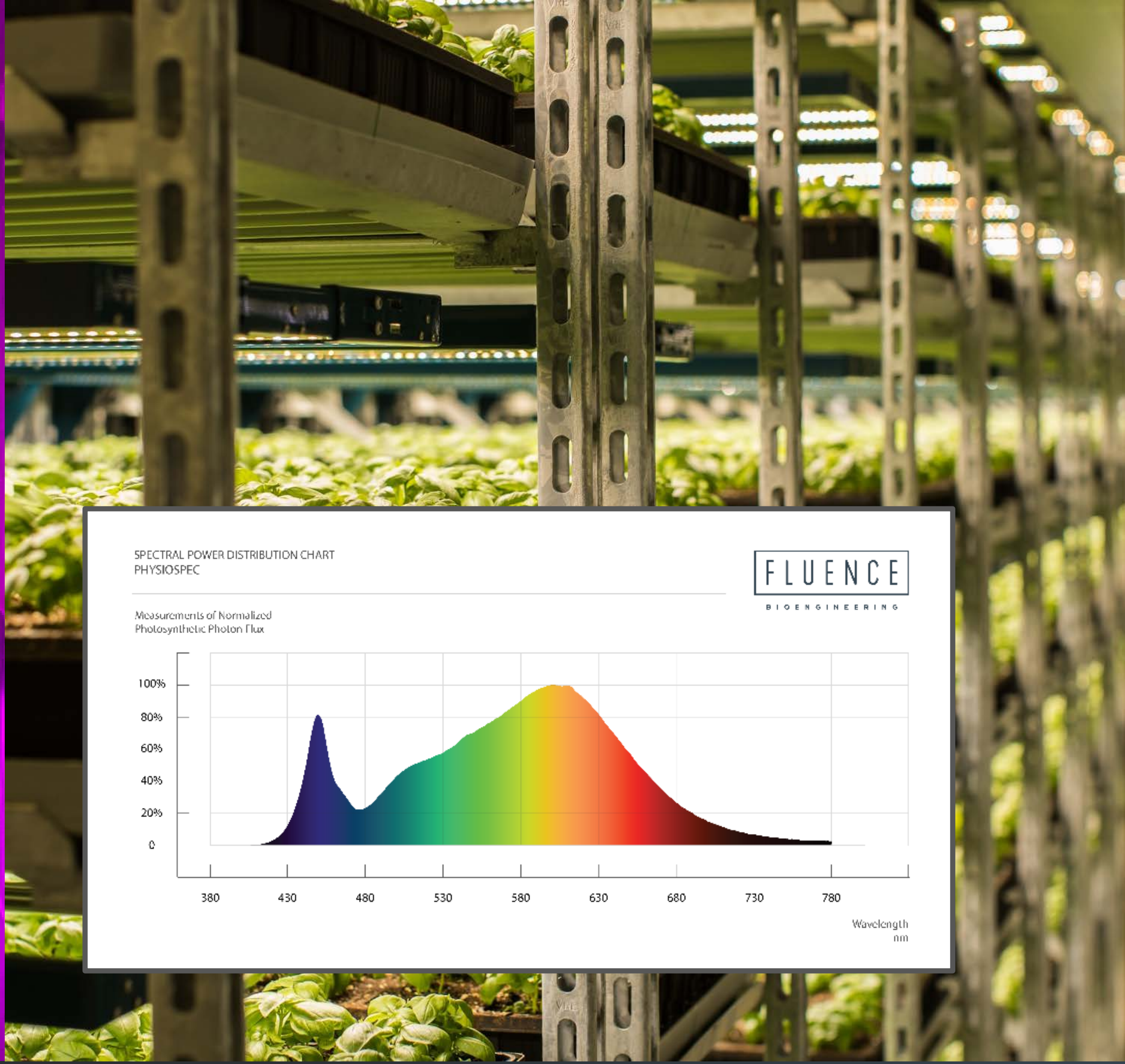
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Wavelength
nm

Economic Analysis of Greenhouse Lighting: Light Emitting Diodes vs. High Intensity Discharge Fixtures

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Mention of a products or vendors does not imply endorsement by Utah State University to the exclusion of other products or vendors that also may be suitable.

Index Words: efficiency, electric lamp, photobiology, return on investment

Abstract. Lighting technologies for plant growth are improving rapidly, providing numerous options for supplemental lighting in greenhouses. Here we report the efficiency and photosynthetic photon flux (PPF) distribution pattern of seven HPS fixtures, ten LED fixtures, three ceramic metal halide fixtures, and two fluorescent fixtures. For each fixture we calculated the efficiency in moles of photons per joule of electricity, and the five-and ten-year electric plus fixture cost per mole of photons. The two most efficient LED and the two most efficient double-ended HPS fixtures had nearly identical efficiencies at 1.66 to 1.70 micromoles per joule. This is a dramatic improvement over the 1.02 micromoles per joule efficiency of the mogul-base HPS fixtures that were in common use 10 years ago. Although the best 380-W LED fixtures had similar efficiencies to 1000-W, double-ended HPS fixtures, the initial capital cost per photon delivered is five to ten times greater. This means that the five- and ten-year electric plus fixture cost per mole of photons delivered to the plant surface were 2.3 and 1.8 times higher for LED than HPS fixtures. LED fixtures, however, can focus photons on specific plant growth areas. Our analysis demonstrates that LED fixtures can be arranged to improve canopy PPF capture efficiency in plant production systems with widely spaced benches. The cost per photon delivered increases rapidly for both fixture types in these systems, however, so arranging plants to efficiently capture photons is an important component of lighting system efficiency. The lowest lighting system costs are realized when an efficient fixture is coupled with effective canopy PPF capture.

Acronyms: *Light Emitting Diode (LED), High Pressure Sodium (HPS), Photosynthetic Photon Flux (PPF)*

Introduction

Rapid advances in lighting technology and fixture efficiency provide an expanding number of options for supplemental lighting in greenhouses. Significant improvements have been made in all three components of fixtures: the lamp (often referred to as the bulb), the luminaire (often referred to as the reflector) and the ballast. Electronic ballasts with double-ended high pressure sodium (HPS) lamp technology are now 1.7 times more efficient than older mogul-base HPS fixtures. LED fixtures are similarly improved and make it possible to focus photons in specific areas.

Lighting technologies vary widely in how radiation is distributed (Fig. 1). There is no ideal pattern for radiation distribution. In large greenhouses with small aisles and uniformly spaced plants, the broad, even output pattern typically found in HPS fixtures provides uniform light distribution and good capture of photosynthetic photons. In smaller greenhouses with spaced benches, the more focused pattern typically

1

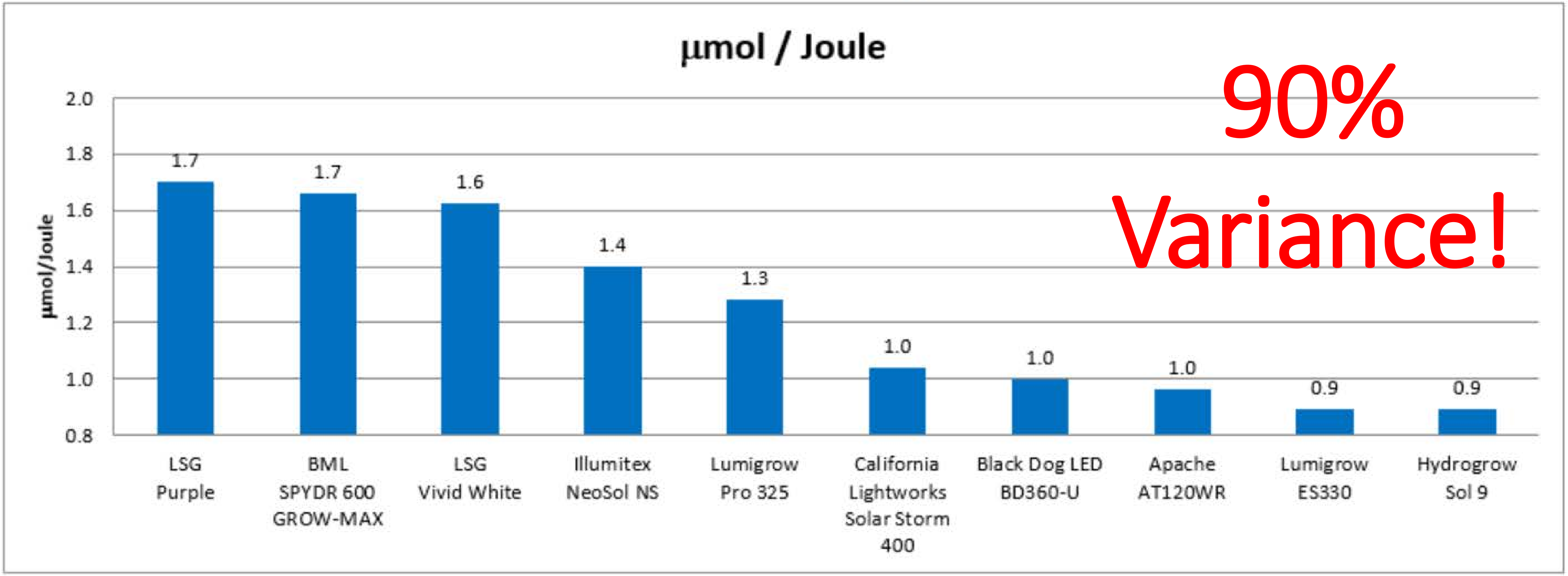
Greenhouse Lighting Comparison Study

June 2014

UtahStateUniversity

FLUENCE

LED Fixture Comparison



HORTICULTURE LIGHTING

Fixture requirements in commercial agriculture

PPF | PPFD | UNIFORMITY | SPECTRUM | EFFICACY | **SIZE** | PROXIMITY

How much space does your lighting system require?

HORTICULTURE LIGHTING

Fixture requirements in commercial agriculture

PPF | PPFD | UNIFORMITY | SPECTRUM | EFFICACY | SIZE | **PROXIMITY**

Space requirements from fixture to canopy?

DRIVING ADOPTION

Removing the barriers:

education + cost

QUESTIONS?

THANK YOU

nick@fluence.science

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