Lighting and Energy

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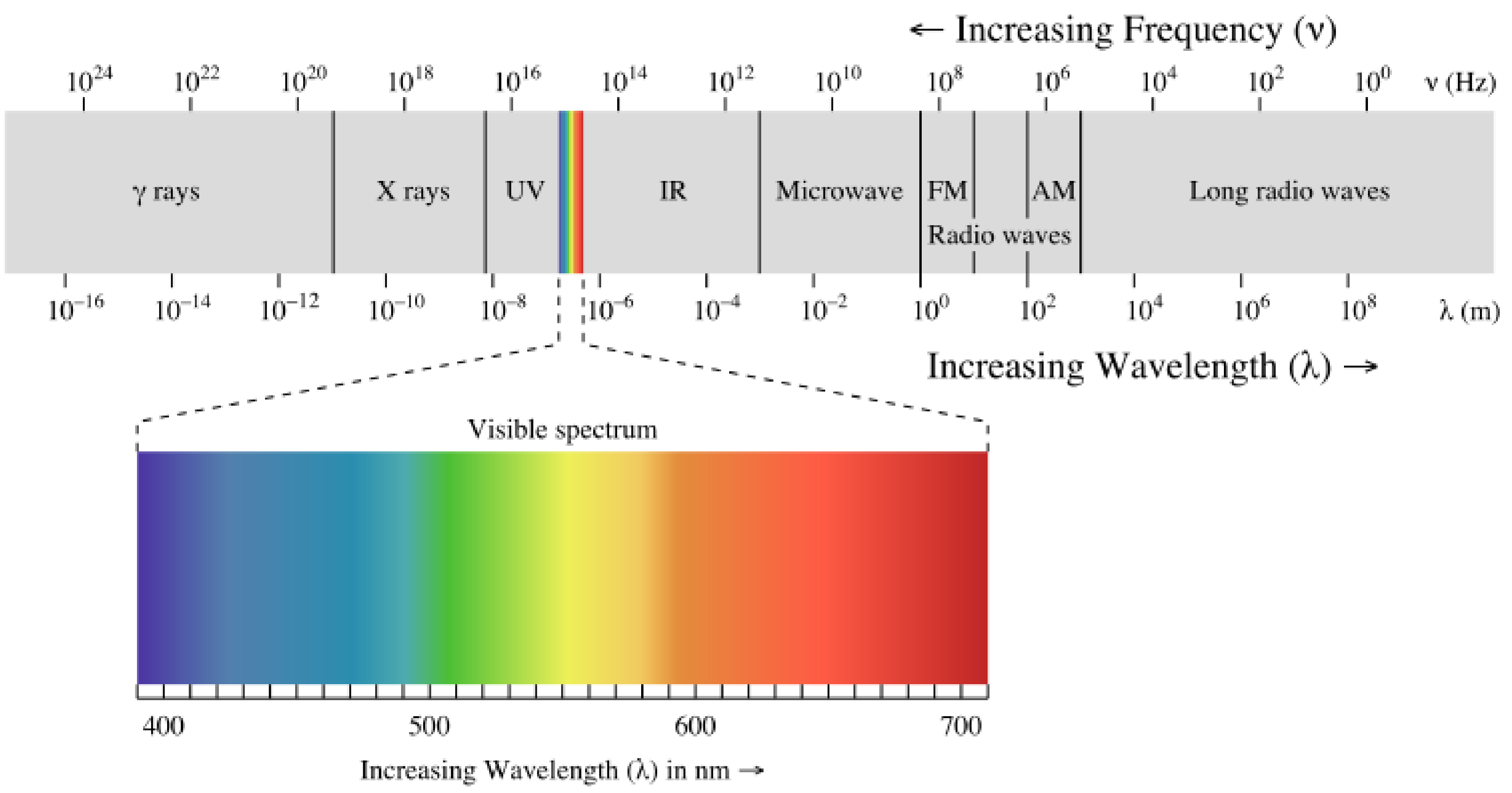
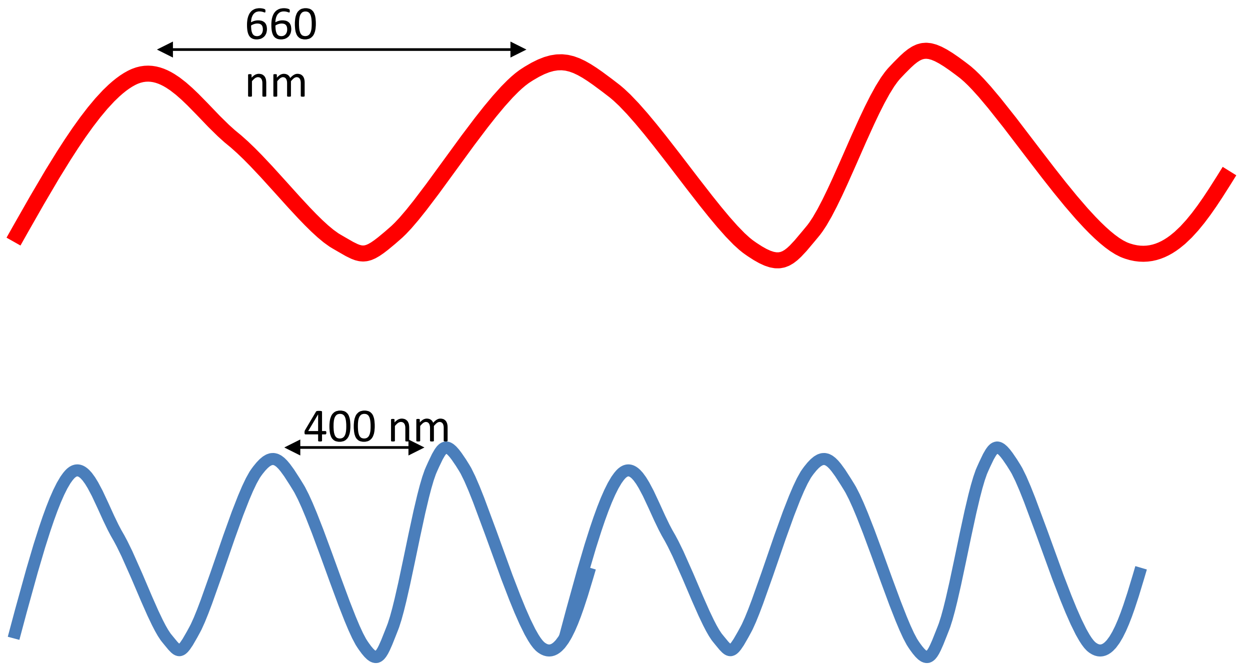
Light exists in both **wave** (with certain frequency and energy) and **particle** (photons with certain intensity) forms





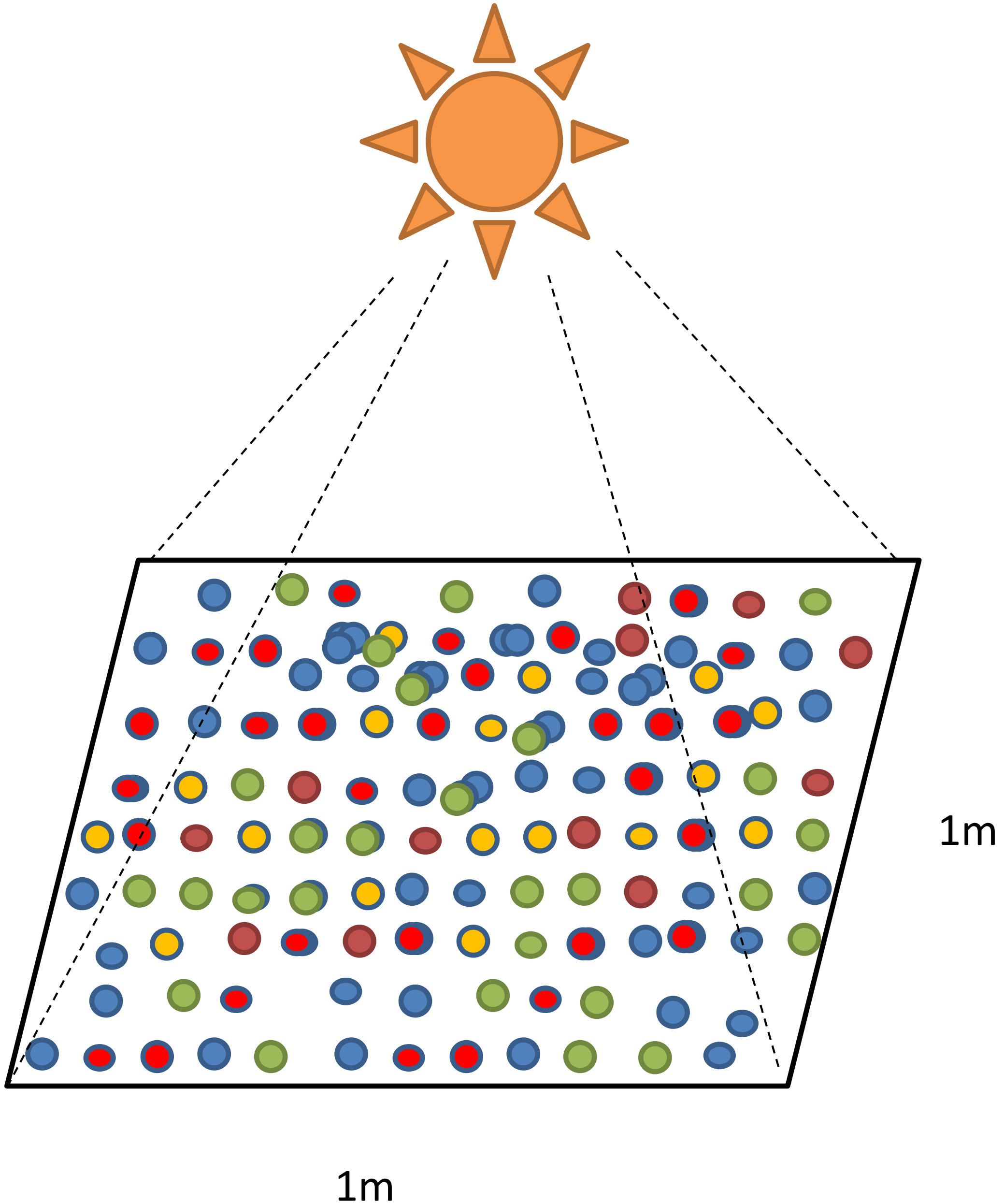
$$Energy = h \times \frac{C}{\lambda}$$

‘h’ is Planck’s constant (4.136×10^{-15} eV s
C is velocity of light (2.99×10^{17} nm/s)
λ is wavelength of photons (nm)

Energy of a blue photon = 4.136×10^{-15} eV s $\times \frac{2.99 \times 10^{17} \text{ nm/s}}{400\ nm}$ = 3.09 eV

Energy of a red photon = 4.136×10^{-15} eV s $\times \frac{2.99 \times 10^{17} \text{ nm/s}}{660\ nm}$ = 1.87 eV

Light intensity is number of photons of light (400-700 nm) incident on a m^2 area in a second



Units of light intensity ($\mu mol/m^2/s$)

One mole contains 6.022×10^{23} entities of a substance

Micro mole is millionth of a mole

$1\ \mu mol/m^2/s = 6.022 \times 10^{17}$ light particles (photons) hitting a m^2 area in one second

Full sun is 2000 $\mu mol/m^2/s$, supplemental lighting provides ~ 100 $\mu mol/m^2/s$

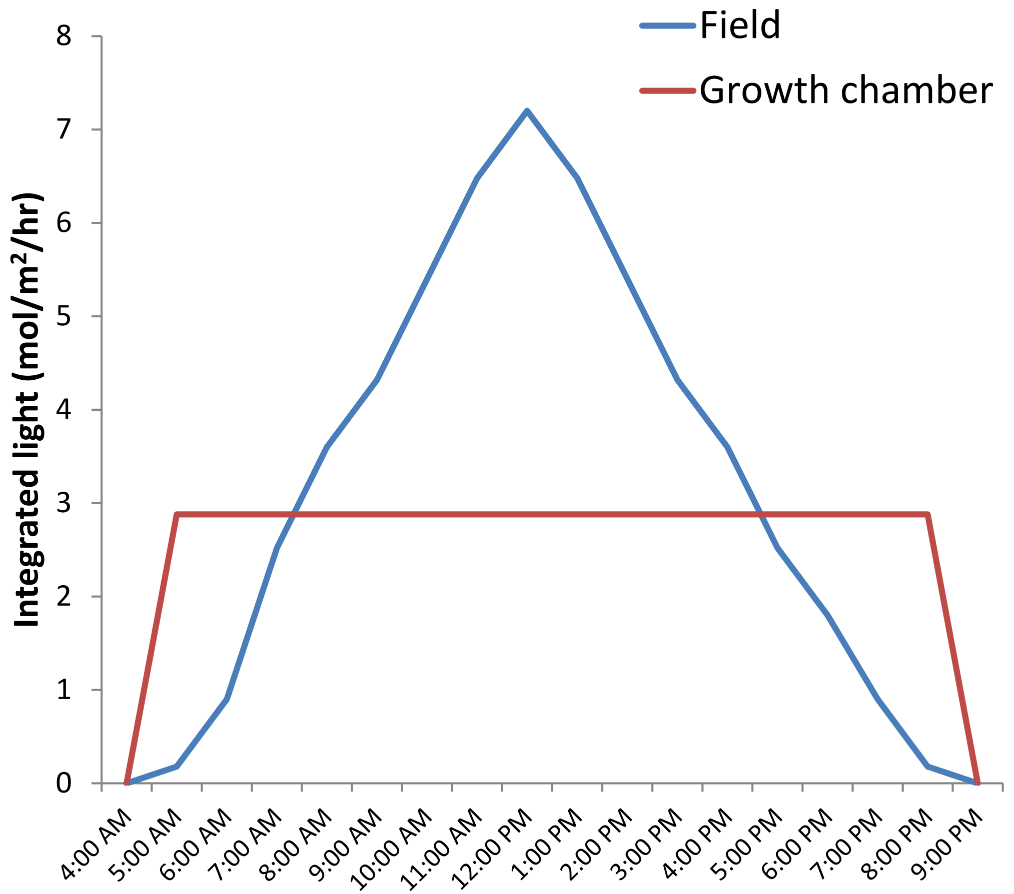
Daily Light Integral (DLI)

Total intensity of light incident on a m^2 area in a day

Units are mol/m^2/d (compare with light intensity)

$$DLI = \boldsymbol{x}\,\frac{\mu mol}{m^2\,s} \times 10^{-6}\,\frac{mol}{\mu mol} \times 3600\,\frac{s}{h} \times \boldsymbol{y}\,\frac{h}{d}$$

Light units: Daily light integral (DLI)

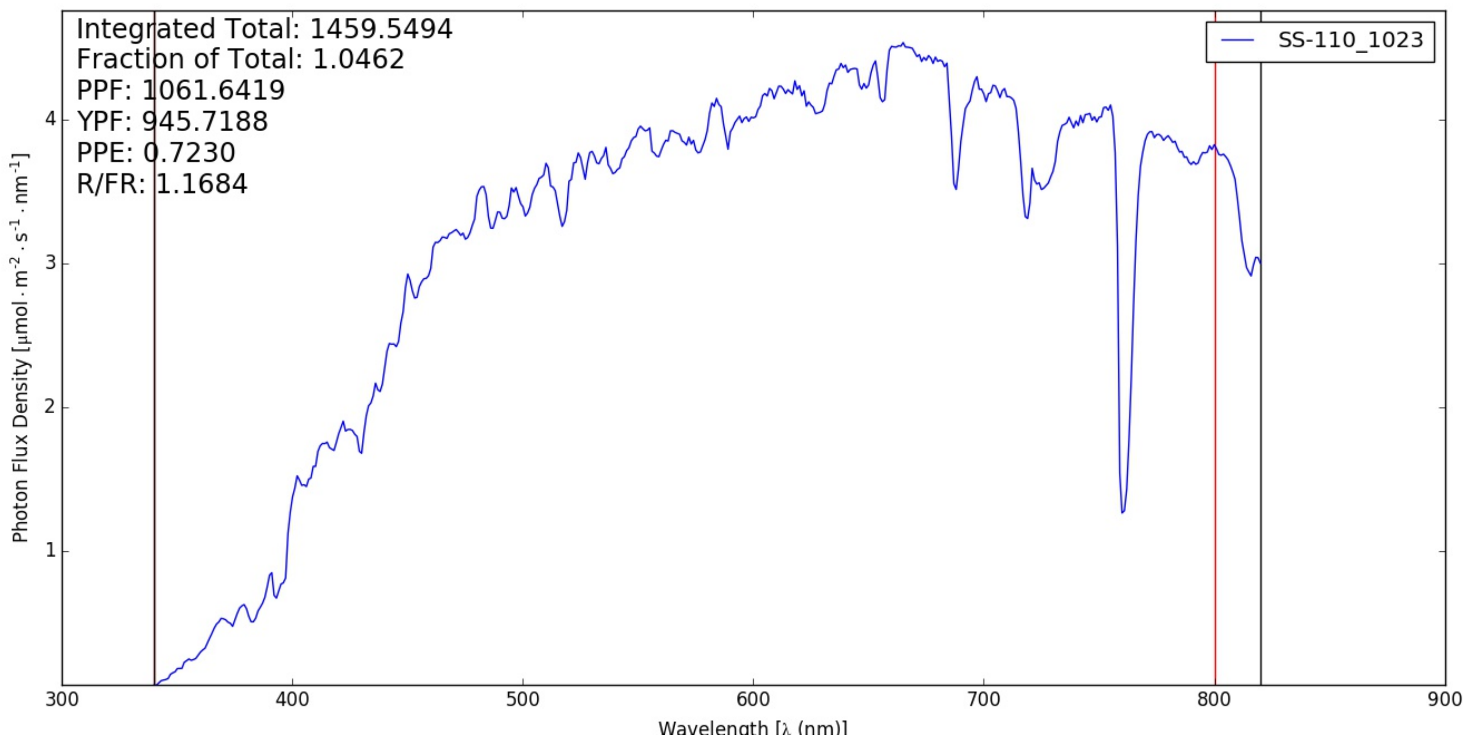


DLI = 48 $\frac{mol}{m^2 day}$

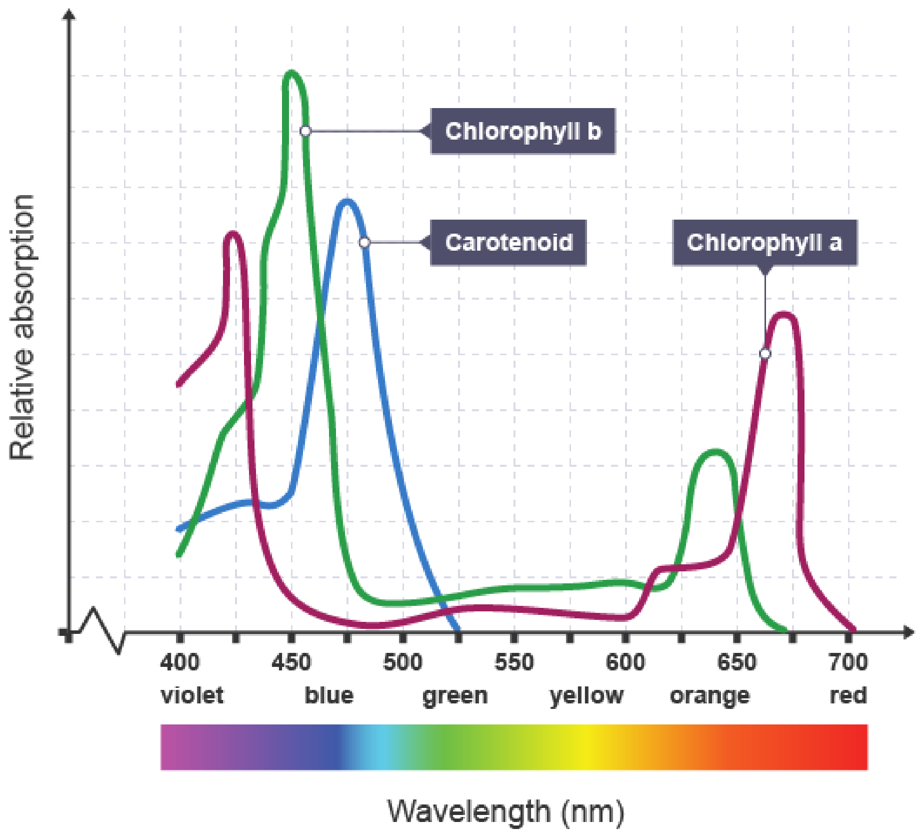
Quantum sensors measure light intensity

Light Composition

- Refers to the relative proportion of photons received at each wave length
- It can be quantified by measuring intensity of individual wavelengths of light
- Units: μmol/m^2/s/**nm**



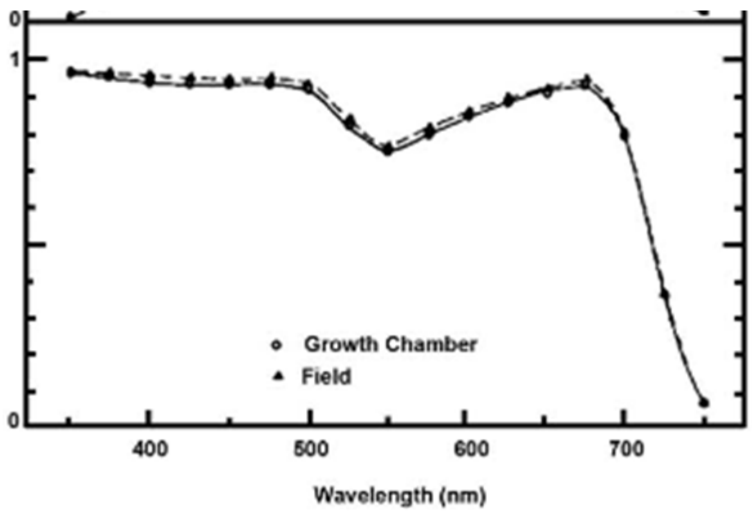
Light absorption vs. Color

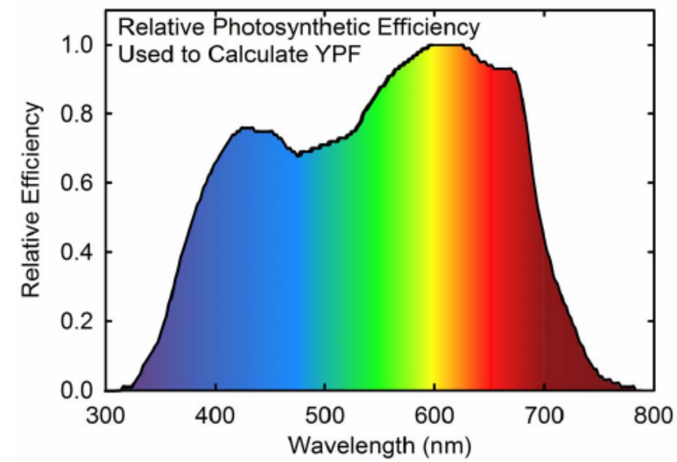


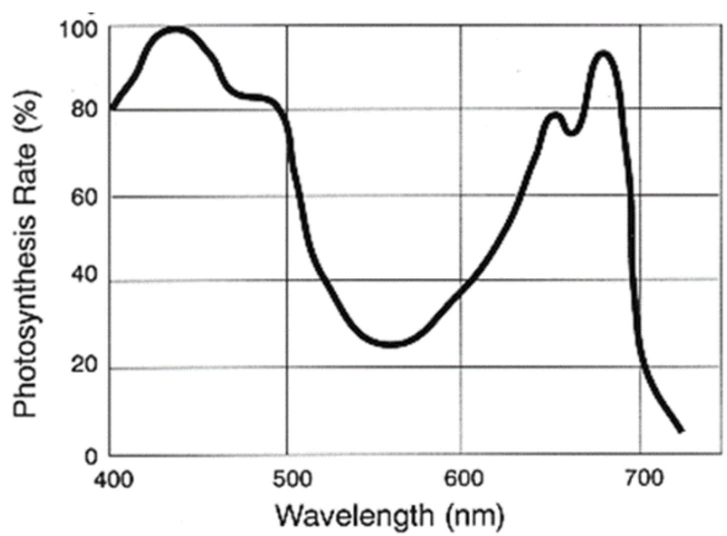
Blue and green light is absorbed by non-chlorophyll pigments

https://bam.files.bbci.co.uk/bam/live/content/zg4tvcw/large

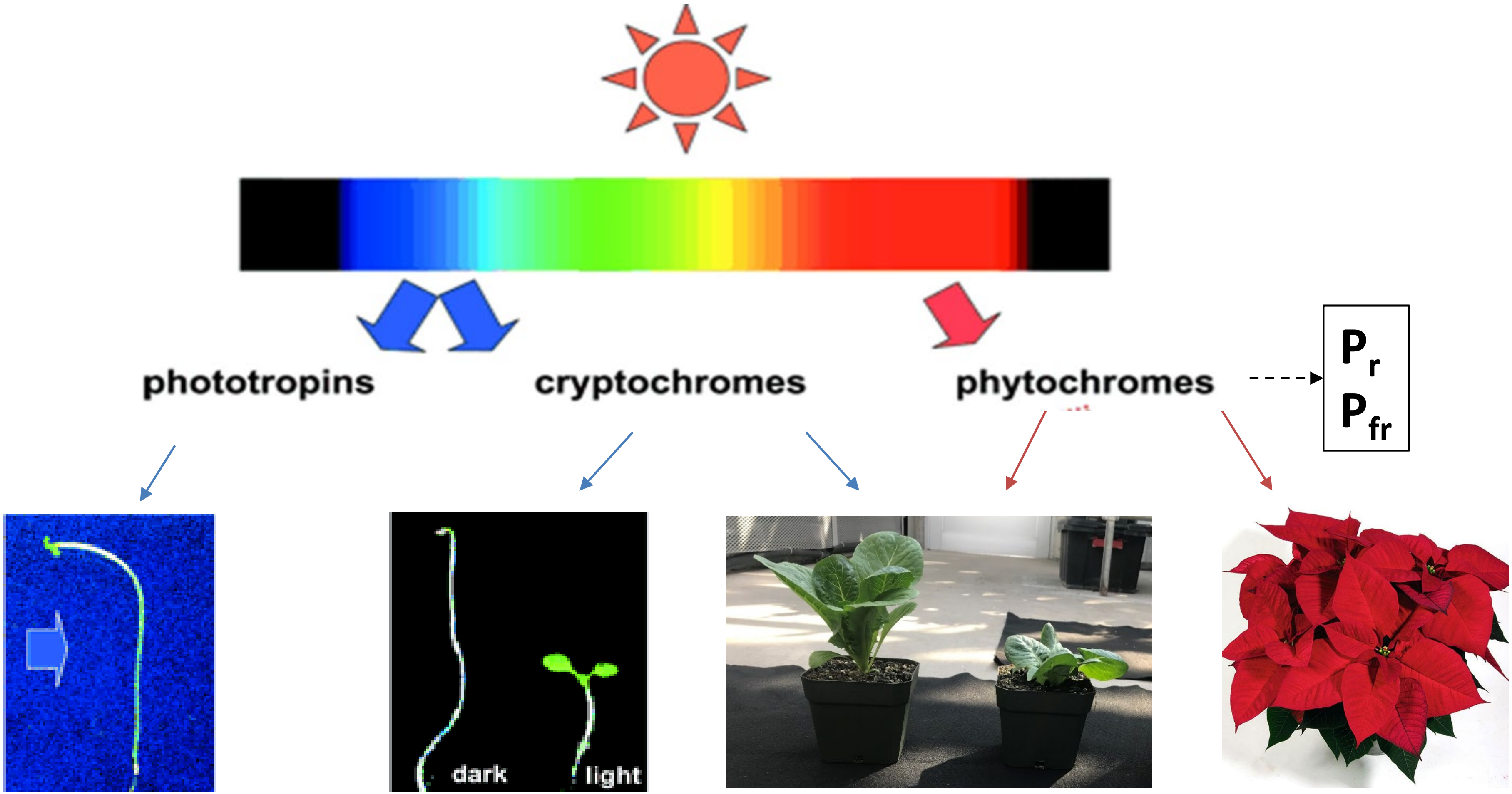
Light composition affects photosynthesis







Light composition effects on plants



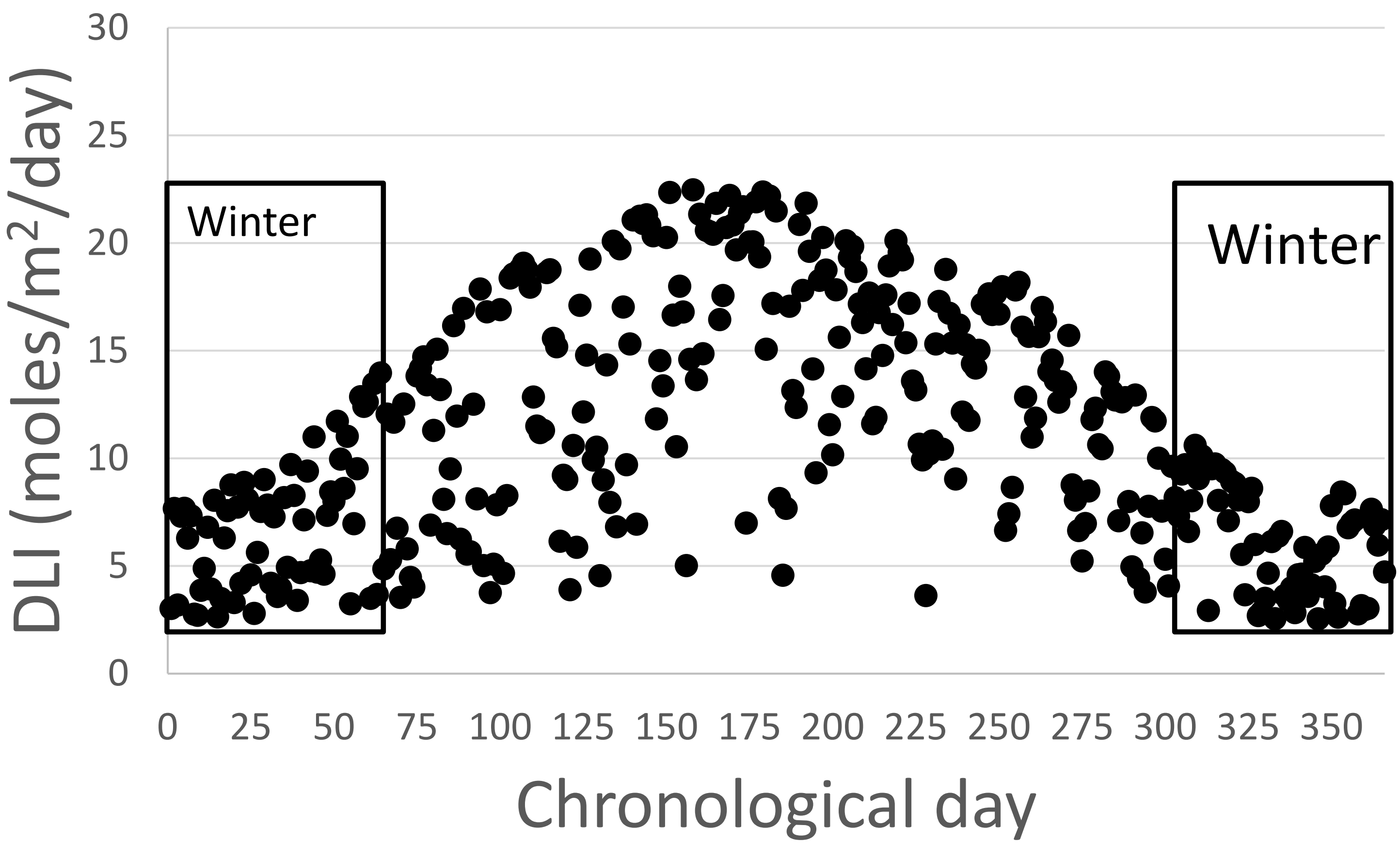
Phototropism

Photomorphogenesis

Photoperiodism

Artificial / Supplemental Lighting

How much sunlight do we get inside greenhouse?



Lettuce requires a daily total of 15 to 20 mol/m^2 of light

Artificial source of lighting is used to provide most (winter greenhouse) of the light

Supplemental lighting

- Provide additional light for photosynthesis during cloudy days or winter months
- Extend photoperiod
- Improve crop quality
- Indirect benefit of heating in winter

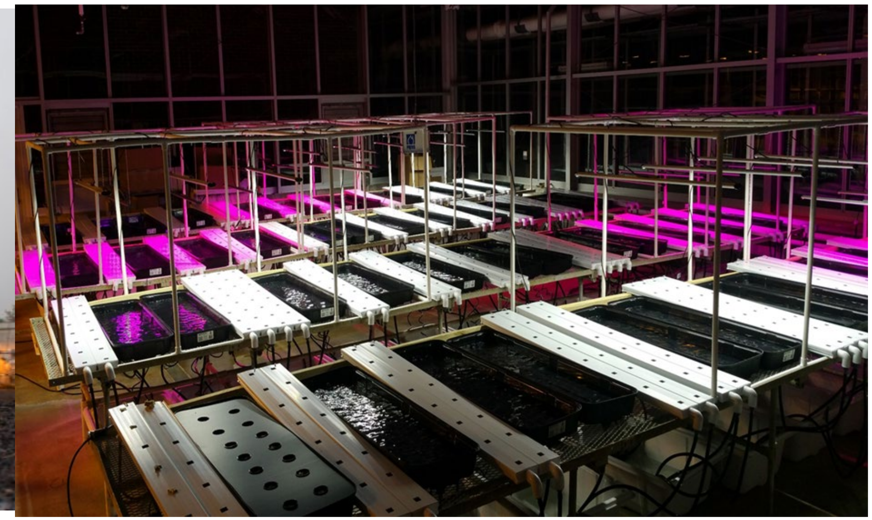
- Can provide 100 to 400 $\mu mol/m^2/s$

Composition of different types of lighting

Light Distribution				
	Light distribution percentage			
Light source	Blue	Green	Red	Far red
Cool-white fluorescent lamp	21	52	24	2
High-pressure sodium lamp	5	51	38	6
Incandescent lamp	2	13	34	52
Metal halide lamp	18	49	25	8
Sun (direct sun and sky)	23	26	26	25

Courtesy: Erik Runkle, Michigan State Univ.

Supplemental lighting options for greenhouse

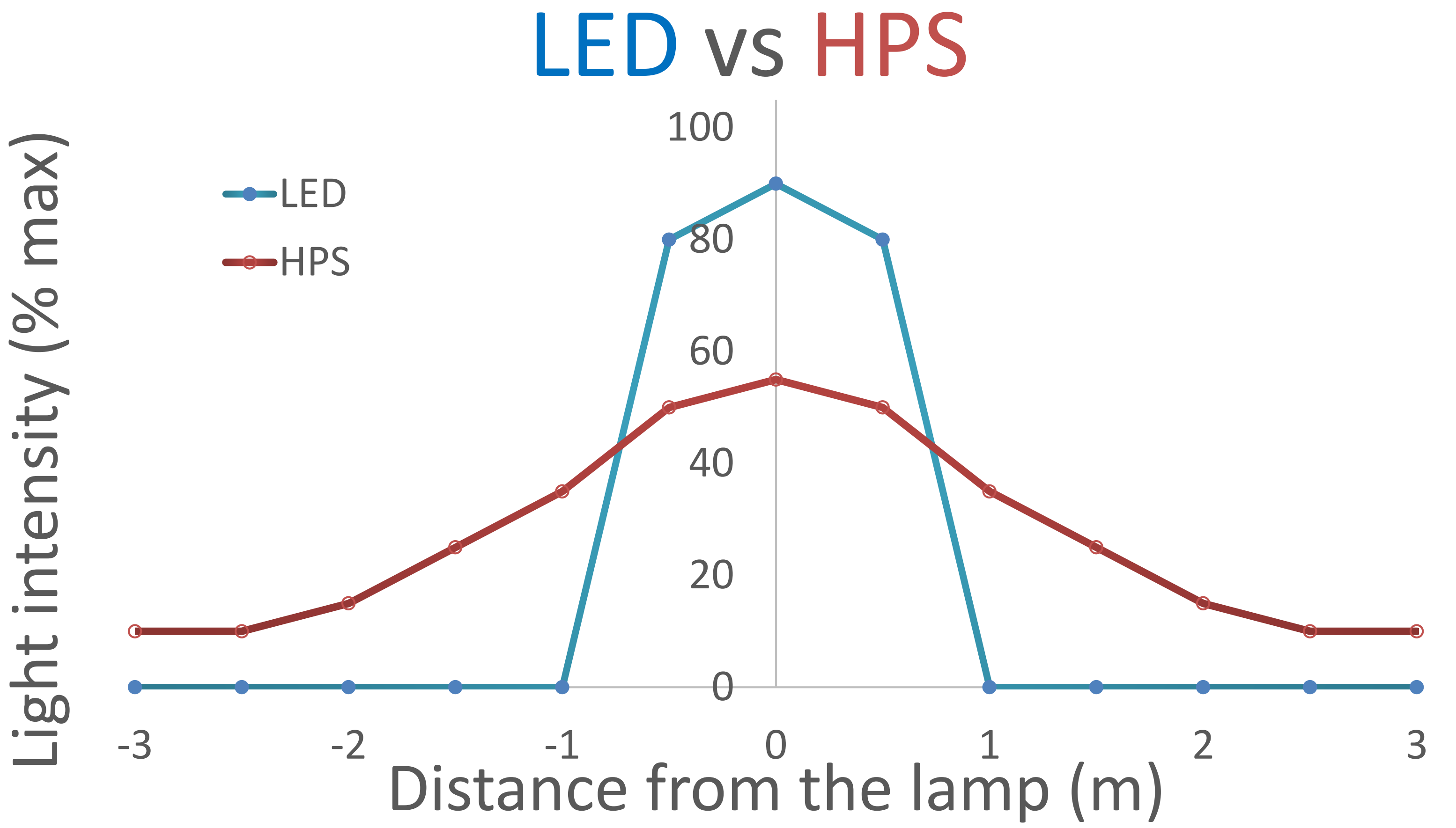


High Pressure Sodium

LED

SE 400W $235

320 W $750

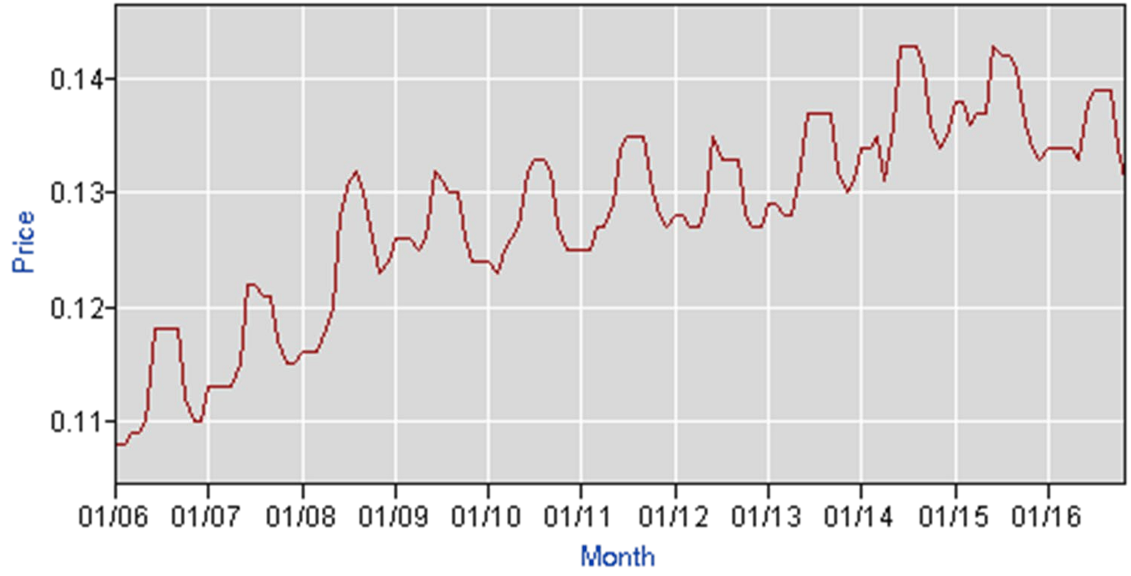

LED vs HPS
LED
HPS
Light intensity (% max)
100
80
60
40
20
0
-3
-2
-1
0
1
2
3
Distance from the lamp (m)

Electrical energy consumption and cost

Kilo Watt hour (KWh): A measure of electrical energy consumption; equivalent to 1000 W of electrical power consumed in an hour.

Electrical companies charge based on number of KWh (5 to 35 cents/KWh)

Look for power (watts) consumption under manufacturer specifications.
Example: HPS lamps: 400/1000 W



Optimal Lighting

$$EUE\ \left(\frac{g}{KWh}\right) = PE\ \left(\frac{mol}{KWh}\right) \times LUE\ \left(\frac{g}{mol}\right)$$

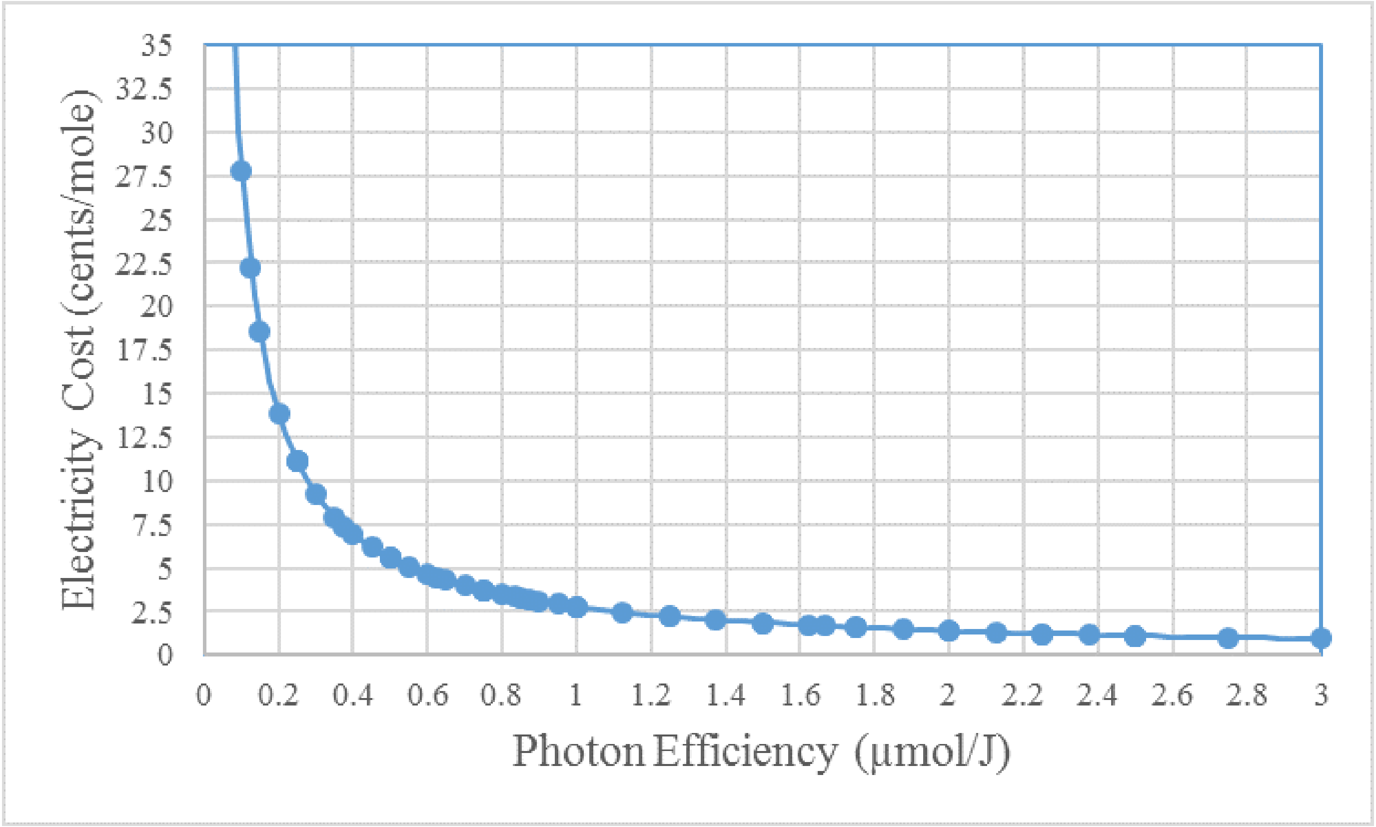
- EUE is energy-use-e efficiency (grams produced per unit energy consumed)
- PE is photon efficiency (mol of light generated per unit of energy consumed)
- LUE is light-use-efficiency (grams produced per mol of light generated)

Photon Efficiency (PE)

- It is light output per unit energy input
- Photon efficiency = $\frac{50}{21} \times \frac{\mu mol/s}{Joule/s}$ = 2.38 $\mu mol/$J

Specs	
Voltage input	120-277 V
Power consumption	21-30 W
Light output	50-62.5 µmol/s
Efficiency	2.0-2.3 µmol/J
Ingress Protection	IP66 (UL/CSA for damp & wet locations)

Electrical Cost vs. Photon Efficiency

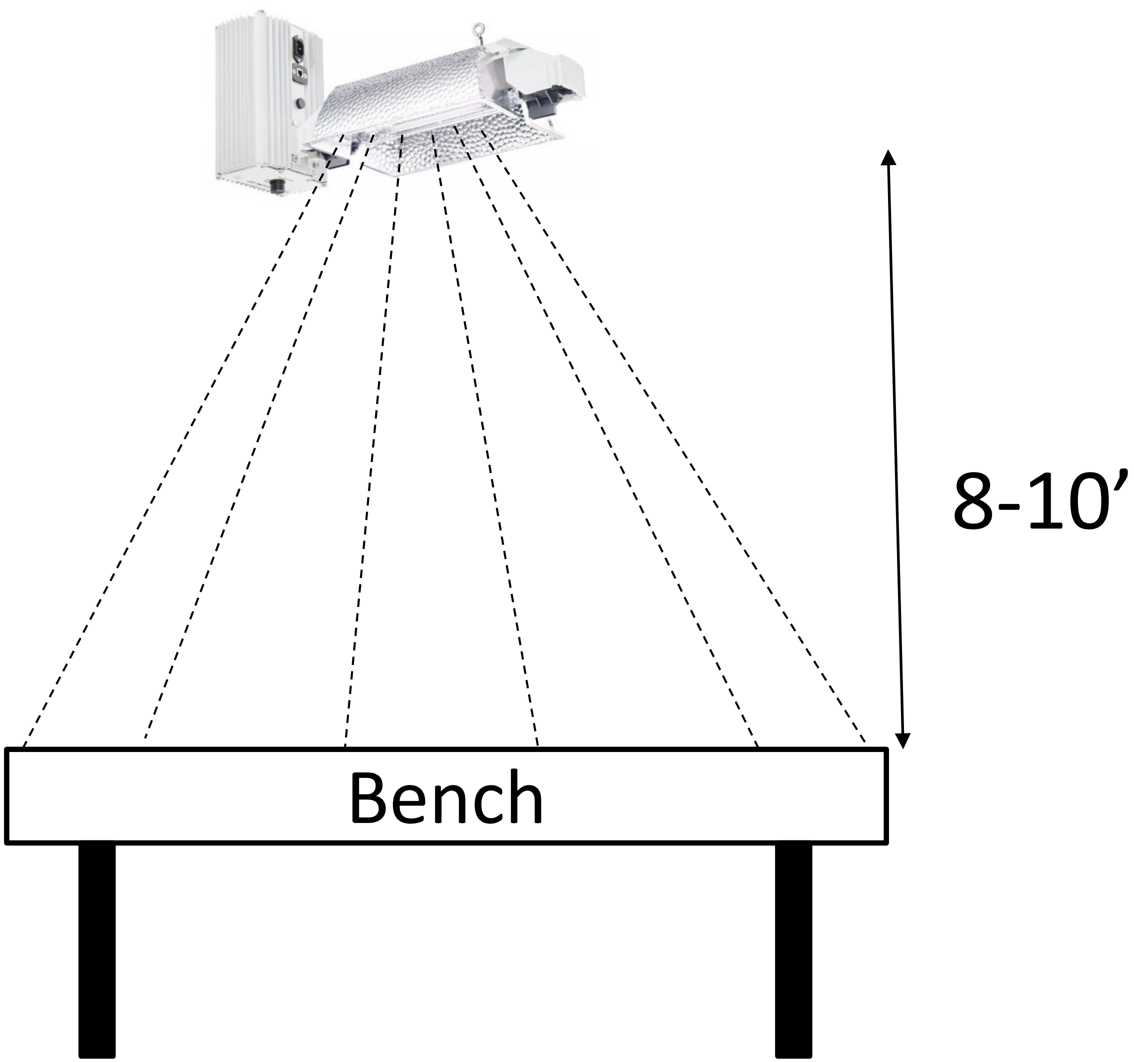


Light-use-efficiency (LUE)

Grams produced per mole of light generated by the fixture

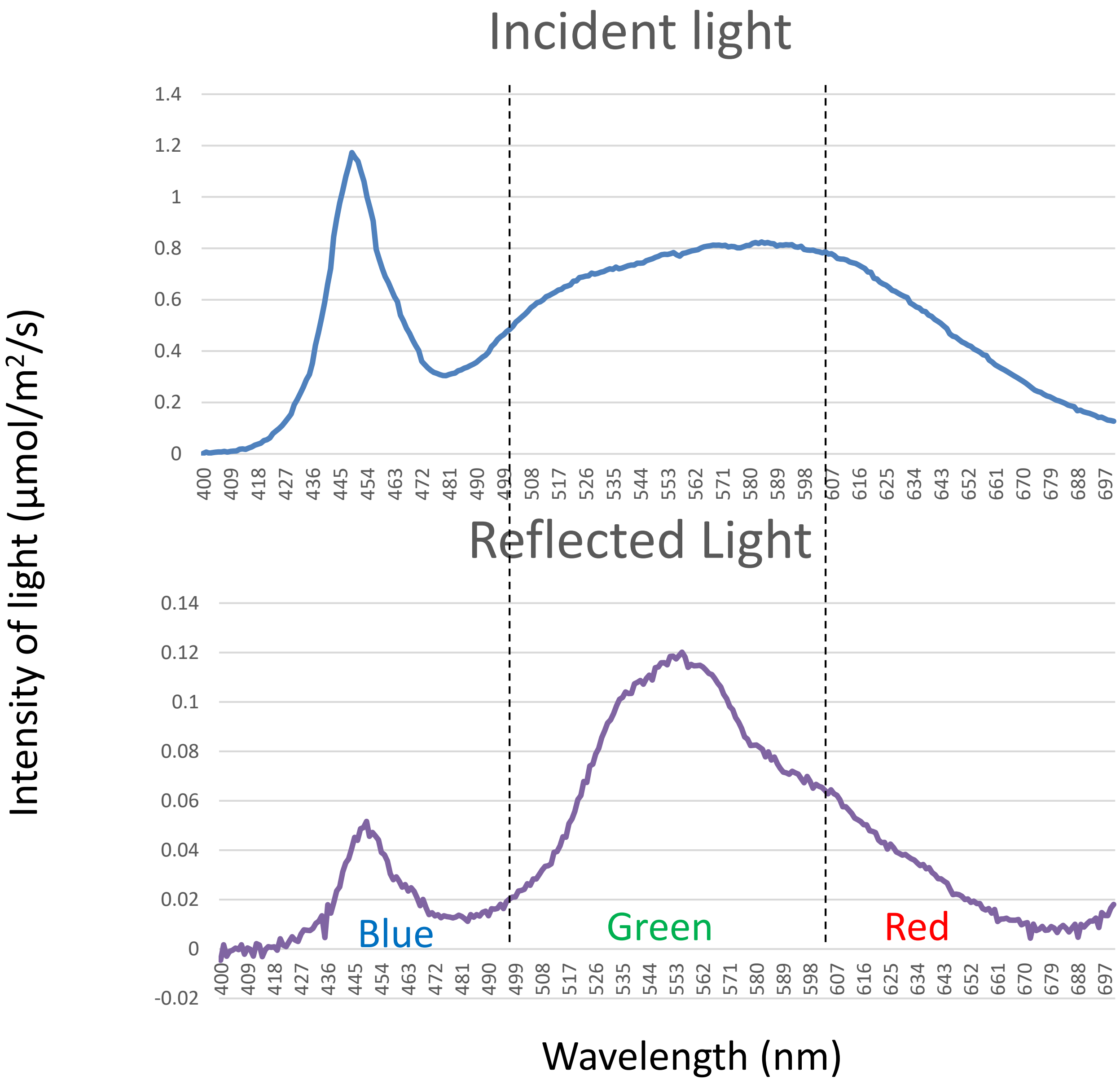
- Fraction of generated light that is intercepted by plants
    - Fraction of intercepted light absorbed by plants
        - Fraction of absorbed light used in photosynthesis
            - Fraction of photosynthate that is converted to economic produce

Light interception

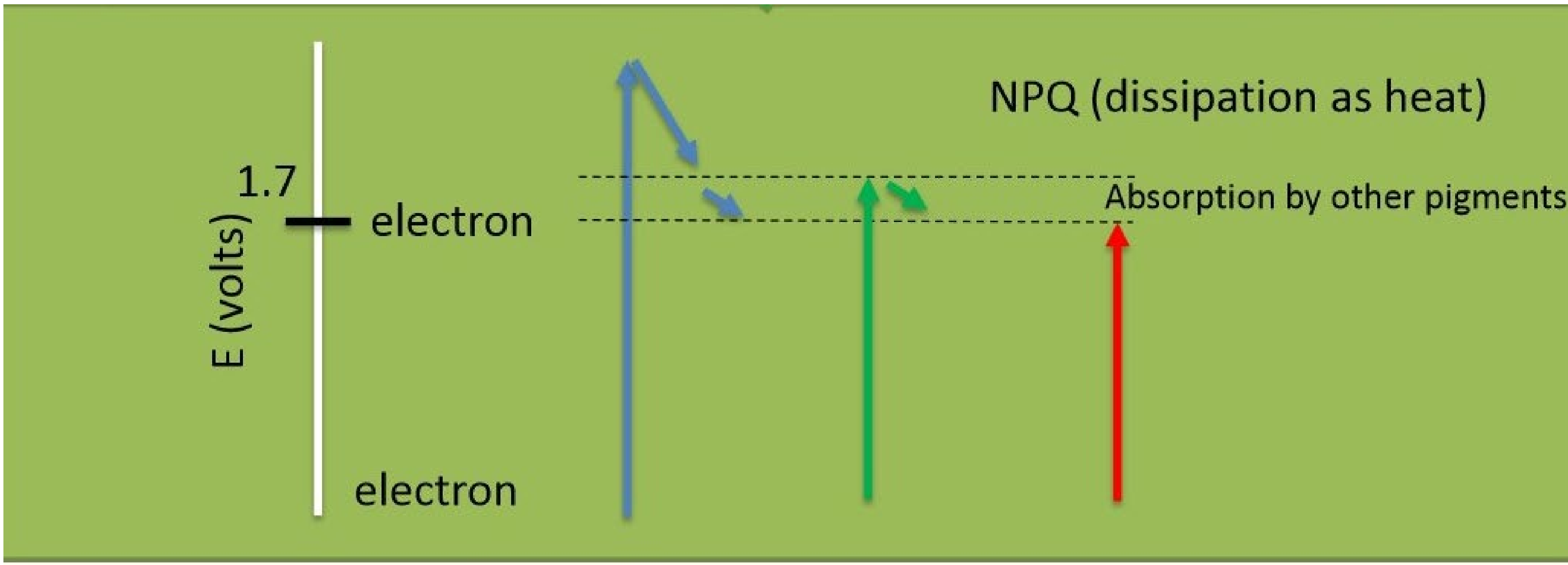


Which set of plants intercept more light?

Light absorption is affected by composition



Fraction of absorbed light used in photosynthesis



Photosynthates to yield

Sugars are used for energy generation, growth, secondary metabolites and osmolytes.

Leafy greens have higher proportion of photosynthates partitioned to economic yield (up to 80%)

Increased anthocyanin as tradeoff for growth

Sunlight

Monetary value of sunlight received annually in a 3000 ft^2 greenhouse is approx. $278000 annually!!