Lighting Technology
Supporting Indoor Agriculture

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For decades, plants have been successfully grown under fluorescent and incandescent lights. As indoor agriculture gains widespread adoption, growers using these technologies are challenged with the lack of photosynthesis active radiation, short lifespans, electric power consumption, and heat generation of these lamps.

More recently, high-intensity discharge (HID) lamps with metal halide (MH) or high-pressure sodium (HPS) bulbs have become a preferred alternative, having the proven ability to deliver quality light output that is more energy efficient. Today, HPS is being challenged by a new generation of solid-state lighting (LED) that not only sets a higher bar for energy efficiency but improves the light spectrum most desirable for plant growth.

The use of LED lighting for plant growth dates to the late 1980s with initial patents awarded in 1991. More recently, NASA embarked upon the application of LED technology to enable "Astroculture" that they deemed essential to long-duration space missions and future colonies on the Moon and Mars.

In its report *Sole Source Lighting for Controlled-Environment Agriculture*, NASA reports:
"The light emitting diode (LED) possesses the most desired SSL (sole source of lighting) characteristics for plant growth, does not require a ballast, and can be manufactured and selected to provide monochromatic light of many different

colors, which can be blended together on arrays to create a range of hues. Hue also can be controlled by varying the intensity of individual colors of LEDs making up a given blend. Because waste heat is removed remote from the photon-emitting surface, LEDs also can be placed closer to crop surfaces … Another important factor is that LED technology continues to improve in electrical efficiency, and production costs are decreasing. All of these attributes combine to make LED a most promising candidate for a range of SSL and indoor-agriculture, now and in the future."

Commercial growers are challenged with the task of evaluating new lighting technologies to solve many of the short-comings of high-intensity discharge (HID) with high-pressure sodium (HPS) bulbs, which are today's most common light for indoor horticulture. That new technology, Wideband LED, is quickly gaining in popularity because it can deliver a superior light spectrum while resolving the economic challenges of electric power consumption.

This white paper offers a comparison of the technologies with the goal of providing the information necessary for horticulturists to make an informed decision.

Plants and humans "see" light differently. In fact, some light that humans are most sensitive to are least used by plants. We categorize the light spectrum as that portion of the electromagnetic spectrum at various frequencies. Light wavelengths are most commonly measured in nanometers (nm), which is equal to one-billionth of a meter.

The visible light range for humans falls between approximately 400 and 700 nm. Although the electromagnetic spectrum extends far beyond the visible spectrum of light, plants primarily use wavelengths in or close to the visible spectrum range. The photosynthetically active radiation (PAR) range for plants also falls in the 400-700 nm range.

Chlorophyll A, chlorophyll B, and beta-carotene are the three pigments found in plants that capture most of the light used for photosynthesis. These pigments are most efficient at capturing light wavelengths that fall in the blue and red bands of light. Chlorophyll A, chlorophyll B, and beta-carotene are not very efficient at capturing green and yellow light.

430-500 nm: Blue

Peak absorption wavelengths for chlorophyll A, chlorophyll B, and beta-carotene fall in this range of light. Chlorophyll A's peak absorption for blue light is around 430 nm, chlorophyll B's peak absorption for blue light is around 453 nm, and beta-carotene's peak absorption for blue light falls around 500 nm. The fact that the peak absorption for all three pigments falls in this wavelength range is why many LED manufacturers produce horticultural lighting systems that target this particular range of light. Metal halides, ceramic metal halides, and fluorescents also emit a good amount of light in this range.

500-570 nm: Green

Even though chlorophyll A, chlorophyll B, and beta-carotene are not efficient at absorbing green light, plants do still respond to it. In fact, there are accessory pigments that harvest the light energy in this range and transfer that energy to chlorophyll, though not to the same degree of chlorophyll A, chlorophyll B, or beta-carotene.

570-590 nm: Yellow

Just as with green light, chlorophyll A, chlorophyll B, and beta-carotene do not have a large response to the yellow light range. It is the accessory pigments in plants that harvest this range of light energy for photosynthesis.

590-620 nm: Orange

Both chlorophyll A and chlorophyll B absorb light from the orange band of the light spectrum. However, it is chlorophyll B that absorbs the most as it is most sensitive to the shorter lengths of red light wavelengths.

620-700 nm: Red

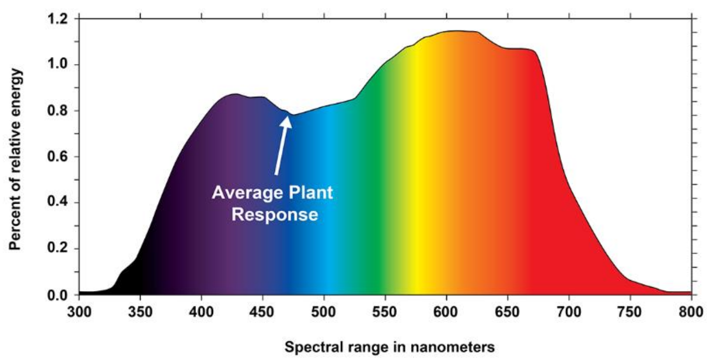
Chlorophyll A and chlorophyll B have their peak absorptions of red light in the 620-700 nm range. Chlorophyll A's peak absorption lies around 642 nm, while chlorophyll B's peak absorption lies around 662 nm. High pressure sodium (HPS), double-ended HPS, and LEDs all target this the red range of light and most effectively match chlorophyll A and chlorophyll B's peak absorption range to the red-light spectrum.

700-750 nm (730 nm): Deep Red

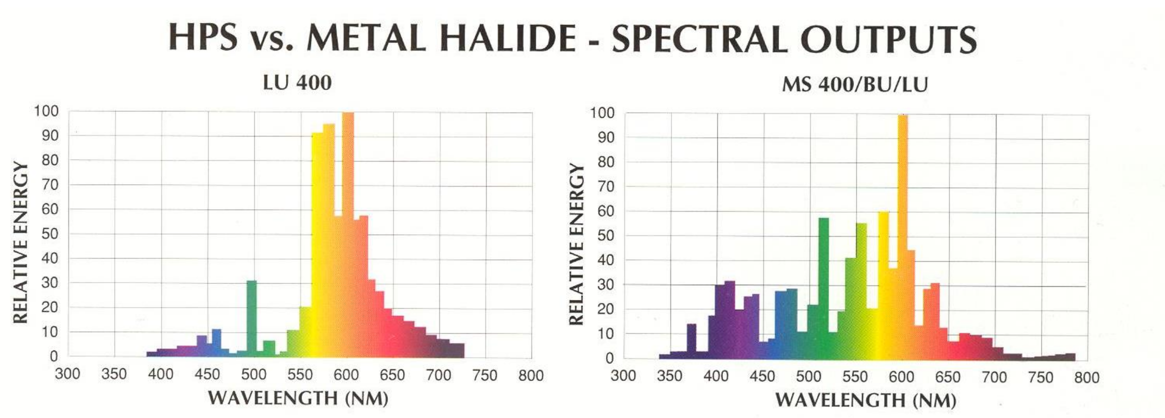
By studying how a plant rests and processes light energy, horticulturists have discovered that exposure to far-red light at the start of their darkness cycle reduces the time needed to rest. By introducing artificial far-red light, they can trick the plants into resting faster, thereby reducing the amount of actual darkness required in a 24-hour period. This is an advantage for growers because they can then extend the light cycle without interrupting the plant's flowering response. Additional light hours equate to more energy for the plant, which, in turn, creates more flower growth and larger yields.

With this knowledge, we can effectively compare the spectral light range of the three most popular artificial light sources: metal halide, high-pressure sodium, and light emitting diodes (LED).

The McCree Curve (aka Plant Sensitivity Curve) pictured here provides the ideal light spectrum for plant growth. We use this as a baseline to compare various lighting device output.



The two charts below map the spectral output generated by High-Pressure Sodium and Metal Halide lights. The LU400 HPS light delivers its most effective light in the orange/red range with only minimal light in the critical blue range. The MS 400/BU/LU metal halide light performs much better across both the blue and red ranges.



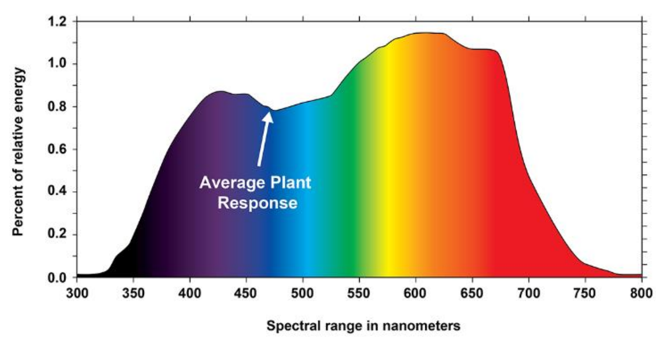
It should be noted that the spectral output of both HPS and MH lamps are when they are new. Within 12-18 months, both light sources will "color shift" which reduces their effectiveness and will need replacement.

High pressure sodium light is optimized for visible light output and provides an excellent solution for lighting large areas at a reasonable cost. It is also strong at directional lighting where contrast is important (and color doesn't matter).
Good examples of this are streetlights used to light up roadways or sidewalks. The reason is that unlike blue light, yellow light doesn't travel far. And since HPS contains almost no blue wavelengths, the light remains in the area. It is ideal for preventing light pollution. This very same lack of blue light that cuts down on light pollution makes the HPS lamp less useful for photosynthesis. Much of the light-energy in the heavily-yellow-weighted spectrum of the HPS is wasted.

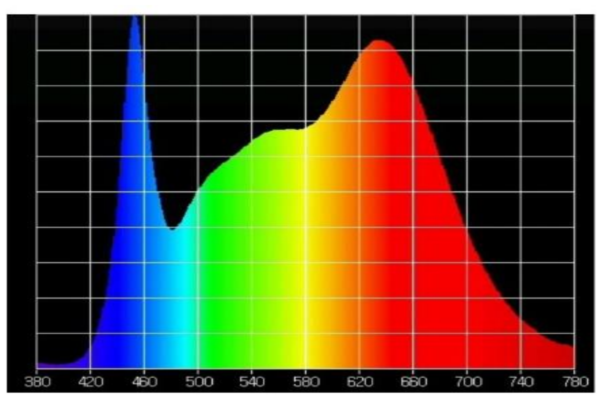
Another issue with HPS is that it emits infra-red radiation in the form of heat, which can stress plants. For this reason, growers are forced to hang HPS fixtures high above plants.

The light spectrum of LED lighting can be fine-tuned to best align with the McCree Curve. As shown below, the US Luminaire LED Grow Light produces a spectral curve that is sustained across the spectrum and offers a spike of blue light and secondary peak of orange/red to maximize plant responsiveness.

Plant Sensitivity Curve



US Luminaire LED Grow Light Spectral Curve



LED grow lights have an advantage because they can be designed to produce the desired light spectrum. This is accomplished by combining multiple techniques: using different materials to construct the semiconductor (light emitter), using various phosphors over the semiconductor, and adding various colored filters. Semiconductors can generate virtually any color light, including non-visible light such as infrared and ultraviolet.

The US Luminaire Grow Light generates the deep-red light which is highly desirable for time-compression of light cycles to create more flower growth and increase crop yields.

LED grow lights are energy efficient. They consume less electric power, a key factor in driving profits to the bottom line. They also produce manageable heat. This not only allows placing the light source closer to the plants (space optimization) but it helps manage the growing temperature environment. Finally, while HPS and MH lights have short lifespans, LED offers over 50,000 hours of operation without any degradation or spectral shift. LED delivers superior ROI compared to any other lighting investment.

When all factors are considered, LED lighting clearly offers a superior lighting alternative to traditional High-Pressure Sodium and Metal Halide for indoor agriculture applications.