

LED Lighting Technology Development

Bob Morrow

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LEDs- Useful Characteristics

- Electrically Efficient
- Long Lifetime
- Low radiated heat
- Emit pure colors without filters (more efficient)
- Intensity can be varied over operational range with little spectral shift
- Rapid on/off capability
- Small size allows unprecedented flexibility in application
- Rugged
 - Solid state
 - Not damaged by repeated on/off cycles
 - No fragile glass envelope
- No hazardous materials (e.g. mercury)



Custom LED Lighting Development

For:

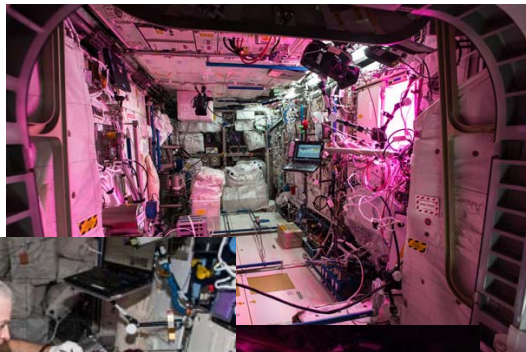
- Unique lighting applications or situations
- Research related to manipulation of plant characteristics
- Investigating impact of control systems and protocols on plant lighting performance
- Investigating impact of physical configurations on plant lighting performance



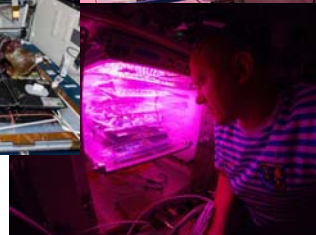
LED Plant Lighting in Space



Astroculture-4
1994
First LED plant
lighting in space



Veggie-01
2014



LEDs- Useful Characteristics

-Can Match Spectrum to Application

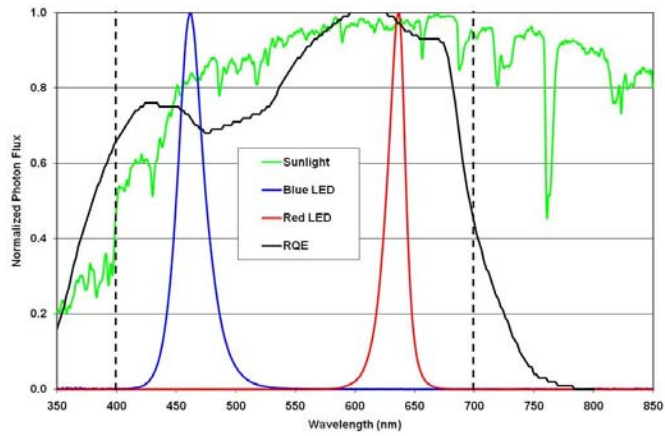


Image courtesy of A.J. Both, Rutgers University



Relative quantum efficiency (RQE) according to McCree, 1972; Sager et al., 1988

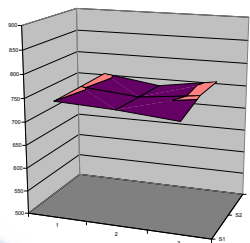


LEDs- Useful Characteristics

Low radiant heat output allows flexible configuration & power savings



Multiple small sources enable increased positional precision



LEDs- Useful Characteristics

-Highly flexible Advanced Lighting Control Systems



HELIAC adaptive lighting system



LED Lighting Design Process – A Brief Overview

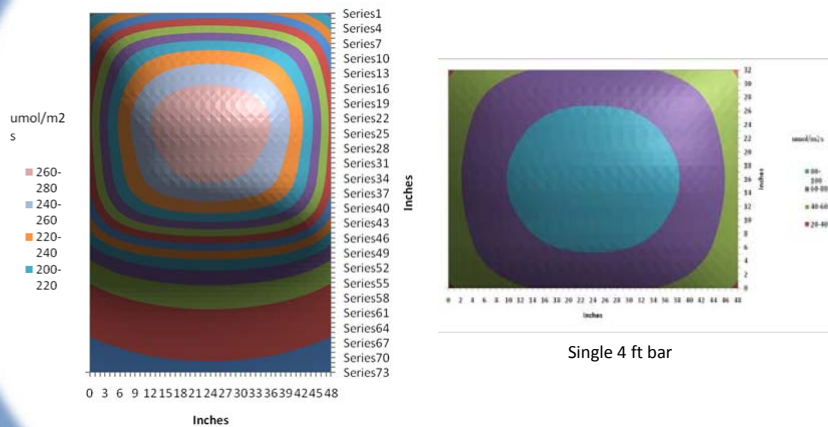


Determine Desired Parameters

Parameter	Desired Value
Type of lighting system desired	Supplemental ___ Sole source ___ Photoperiodic ___
Lighting configuration desired	Planar (overhead) ___ Intracanopy ___ Other (describe) _____
LED light spectrum (wavebands) desired and intensity at the various spectral peaks (desired measurement units- micromol/m ² /s)	UVA (400nm) ___ Blue (450 nm) ___ Green (540nm) ___ Red (630nm) ___ Far red (730nm) ___ White ___ (color temperature _____) Other (define) _____
Desired AC power source	120 VAC ___ 220VAC ___ Other (define) _____
Type of control interface desired	Manual ___ Computer ___ Customer Provided ___ If Customer Provided, select desired interface: 0-10V ___ 0-5V ___ 4-20mA ___ Other (specify) _____
Control resolution	Number of zones Size of zones to be illuminated:



LED Intensity and Uniformity Model

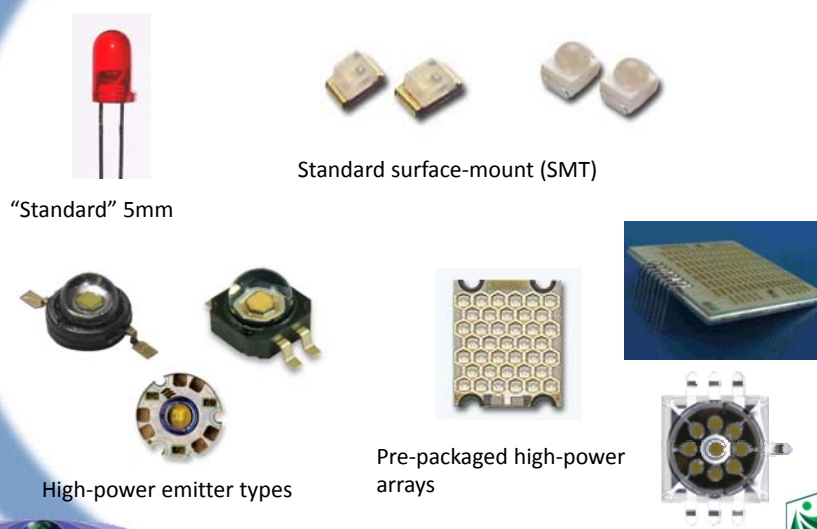


Single 4 ft bar

Eight 4 ft bars about 5 inches apart at 8 inches from surface



LED System Design





"Standard" 5mm

Standard surface-mount (SMT)

High-power emitter types


Pre-packaged high-power arrays



LED System Design

- Optics
 - Commercially available
 - Custom / application specific

• Remote Phosphor



Conventional LED Lighting System

The ChromaLit™ Solution

ChromaLit™ Lighting System

Optics

needs no diffuser

Increases light extraction

lowers system operating temperature

which results in 30% improved efficacy



Diffuser

White LED

Blue LED

Substrate

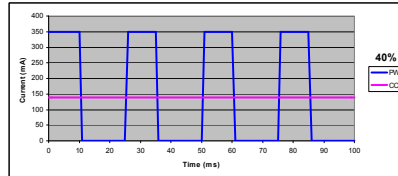
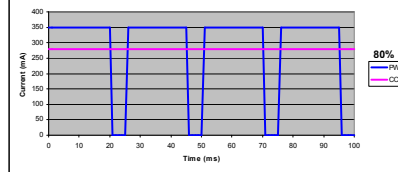
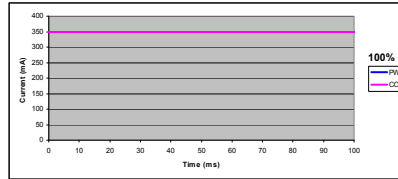
Multiple ChromaLit™



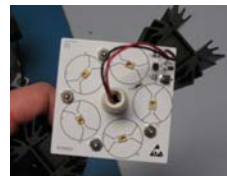
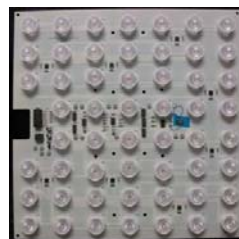
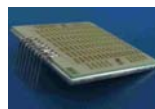
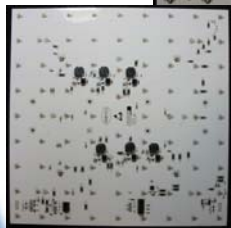
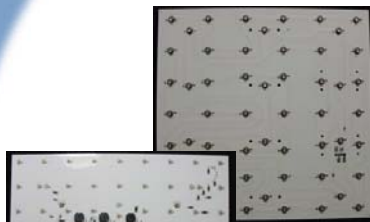
http://www.futurelightingsolutions.com/en/technologies/Pages/remote_phosphor.aspx

LED System Design

- LEDs operate best when driven in current control mode
- Controls may range from simple manual adjustments to sophisticated computer controls
- Simple vs. complex. Complexity impacts reliability
- RGB control to balance color
- Dimming – can be linear and/or PWM
- Optical and/or thermal feedback
- “Intelligent controls” - compensate for aging, color shift
- Light out detect – shorted or open LEDs
- Balance multiple strings of lights



LED Circuit/Mounting Boards



LED System Design

Thermal Management

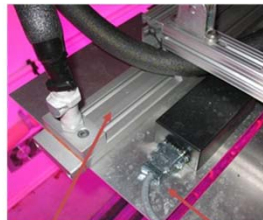
Source	Efficacy (lm/W)	Heat Loss (%)		
		Radiation	Convection	Conduction
Incandescent	15	90	5	5
Fluorescent	90	40	40	20
HID	100	90	5	5
LED	75	5	5	90

- Heat must be effectively managed to ensure long life and high performance, especially with high-power LEDs ($\geq 1\text{W}$)
- Cooling mechanisms
 - Direct conduction to a mounting surface
 - Natural convection
 - Forced-air (fans)
 - Liquid cooling

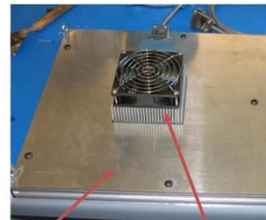


LED System Design

Passive or active cooling



Chilled water conduit



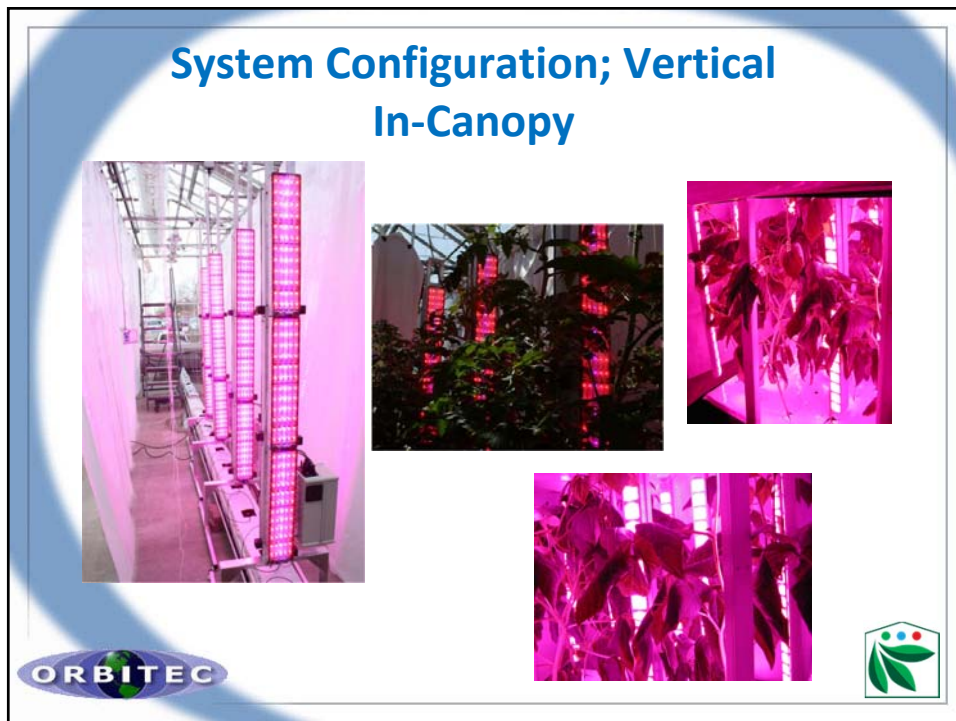
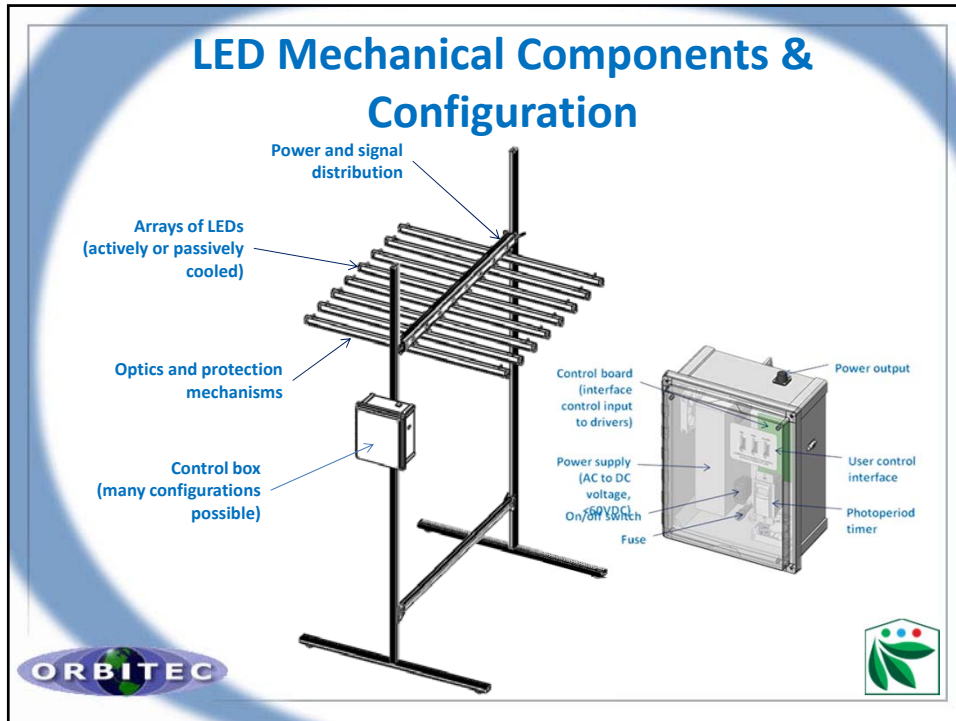
Fan/heat sink combination

LED panel

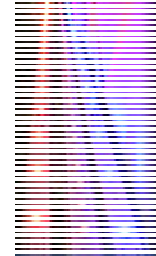


http://www.ledtransformations.com/Lightfair_5-28-08.pdf. Accessed 2-2-2012





System Configuration; Overhead Bars



Large Sole Source Lighting Arrays



Factors Impacting Design

LEDs have a very long life, but....

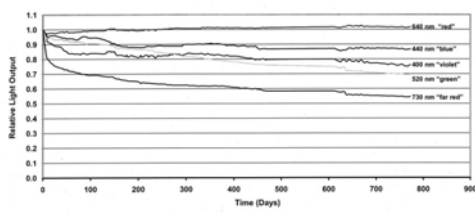
Life effected by;

- Heat
- Shock/vibration
- Environment
- Component quality
- Power quality




Light related injuries or disorders

Intumescence Development

- Lack of UV
- R promotes/FR inhibits
- Species and cultivar dependent



Different colors degrade differently, phosphors degrade faster than LED

Factors Impacting Design

Safety

Vision

No high energy wavebands unless using UV LEDs
 Consensus at this point is that LEDs pose same vision hazard as other lamps, and the same precautions should be used as for any intense lighting source.

Electrical

Generally low voltage DC, but AC/DC power supplies are source of electrical hazard

“Green” issues




Disposal

- Most power LEDs are RoHS (Reduction of Hazardous Substances) compliant
- RoHS restricts the use of 6 hazardous materials: lead, mercury, cadmium, Hexavalent chromium, Polybrominated biphenyls (PBB), and Polybrominated diphenyl ether (PBDE).

Light pollution

LEDs may have less impact than HPS, but it depends on;

- color
- location (height)

LED System Cost Drivers

- LED device cost
 - waveband
 - quality/manufacturer
 - phosphors
 - type of mounting
- Large number of devices used
 - parts cost
 - assembly labor
- Power systems
 - use DC instead of AC power
- Thermal control
 - heat sinks
 - fans/active cooling



Future Tools for LED Lighting Design

- Improvements in LED “chemistry”
 - More wavelengths
 - Higher output devices (UV, Far red)
 - More electrically efficient devices
- Improvements in LED mounting & packaging
 - Effective heat sinking
 - Reflectors
 - Lenses
- Mass production techniques
 - Individual LED mounts
 - LED arrays
- Increased understanding of using light to achieve specific horticultural goals
 - crop timing
 - yield
 - antioxidant content
 - organoleptic and ornamental quality
 - post harvest shelf life
- Physical configurations optimized for specific horticultural applications
- Integration with other systems such as greenhouse heating & atmospheric control

