

LED Streetlights and the Environmental - Environmental Issues -

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It all started with ...

- **Desire to reduce energy use**
- **The buzz around LED streetlighting**



Environment Assessment or Impact

For almost all of human history,
night meant total darkness ...



Environmental Issues



• **Light Pollution = Sky glow**

• **Light Trespass = Neighbor to Neighbor Complaint**

• **Circadian Cycles = Effects on Flora, Fauna, People**



Women in industrialized countries have a much higher rate of breast cancer, especially shift workers



Melatonin production

Occurs in the dark

When light is
introduced, melatonin
is suppressed



Similar Solutions

- **Establish Lighting Zones**
- Luminaire distribution = IES BUG Ratings
- Lighting Level Management
- Activity Levels or Curfews Establishment
- Spectral Distribution = Minimizing short wavelength light

Lighting Zones

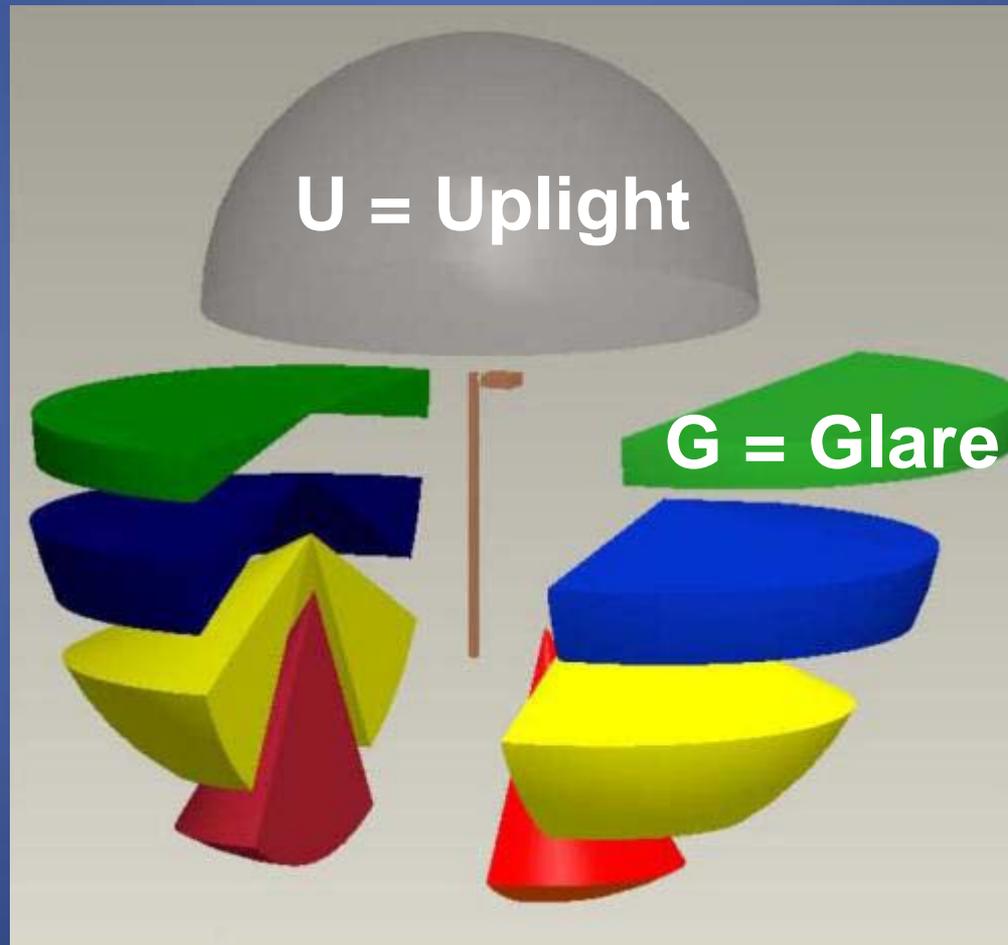


- ***LZ0 - No Ambient Lighting***
- *LZ1 - Low Ambient Lighting (default residential, small towns)*
- *LZ2 - Moderate Ambient Lighting (default light commercial, high density or mixed use residential)*
- *LZ3 - Moderately High Ambient Lighting (default for large cities' commercial district)*
- ***LZ4 - High Ambient Lighting (not a default zone)***

Similar Solutions

- Establish Lighting Zones
- Luminaire distribution = IES BUG Ratings
- Lighting Level Management
- Activity Levels or Curfews Establishment
- Spectral Distribution = Minimizing short wavelength light

IES TM-15 – Outdoor Luminaire Classification System (BUG)



**B =
Backlight**

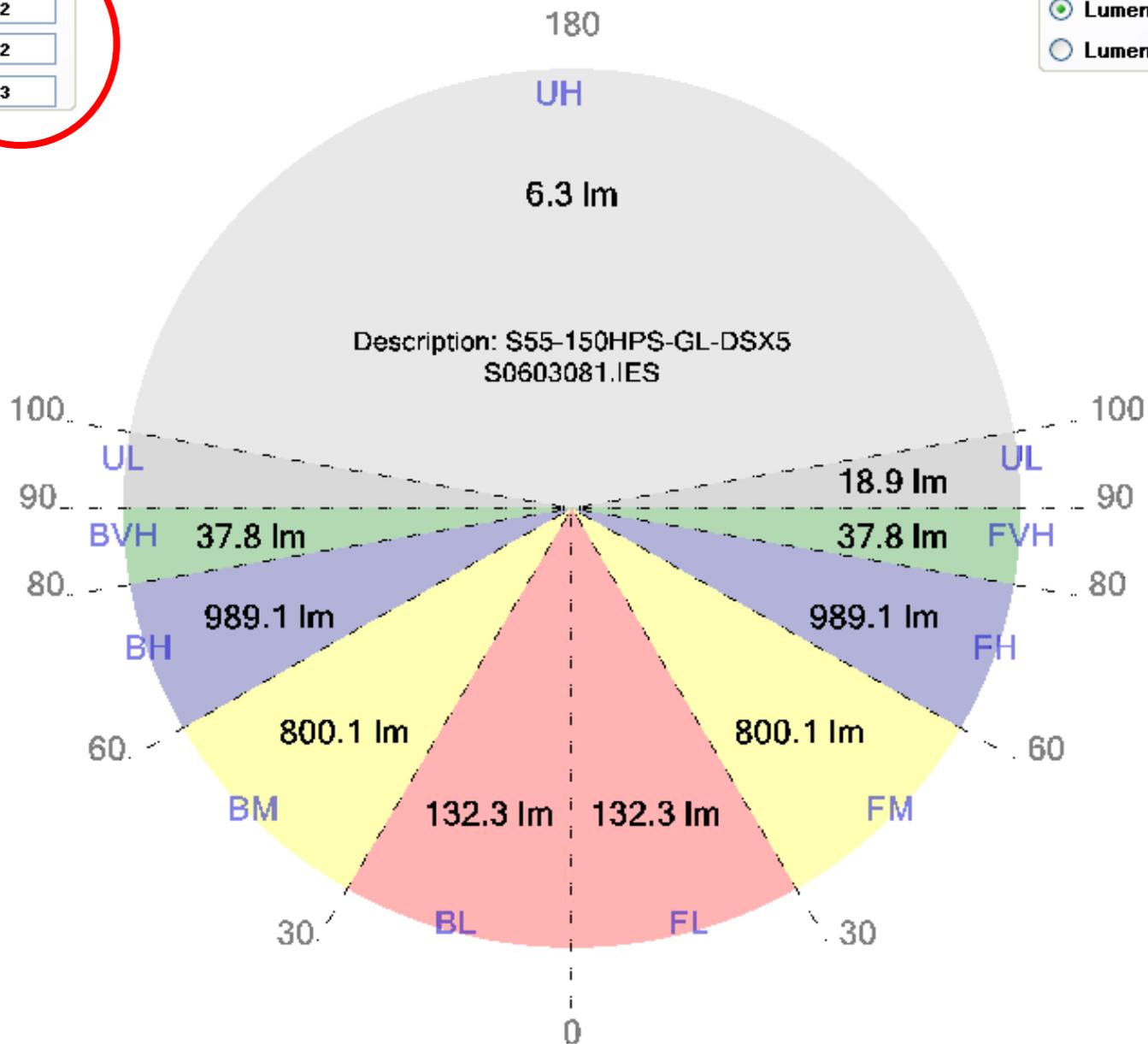
New Luminaire Classification System

Class

B: 2
U: 2
G: 3

Options

Lumen
 Lumen %



Off Site Impacts (MLO - Option A) - Maximum B Ratings

TABLE C-1		LZ 0	LZ 1	LZ 2	LZ 3	LZ 4
Allowed Backlight Rating*, **						
Greater than 2 mounting heights from property line		No Backlight Rating Limits				
Reduced Backlight Ratings	1 to less than 2 mounting heights from property line	B1	B2	B3	B4	B4
	0.5 to 1 mounting heights from property line	B0	B1	B2	B3	B3
	Less than 0.5 mounting height to property line	B0	B0	B0	B1	B2

Closer to the property line, the more stringent "B" value

Off Site Impacts (MLO - Option A) - Maximum U Ratings

**Table C - 2 Maximum Allowable Uplight
(BUG) Ratings - Continued**

TABLE C-2	Lighting Zone 0	Lighting Zone 1	Lighting Zone 2	Lighting Zone 3	Lighting Zone 4
Allowed Uplight Rating	U0	U1	U2	U3	U4
Allowed Uplight Rating for street or Area lighting	U0	U0	U0	U0	U0



**U0 uplight for street
lighting**

Off Site Impacts (MLO - Option A) - Maximum G Ratings

**Table C - 3 Maximum Allowable Glare
(BUG) Ratings - Continued**

TABLE C-3	Lighting Zone 0	Lighting Zone 1	Lighting Zone 2	Lighting Zone 3	Lighting Zone 4
Allowed Glare Rating	G0	G1	G2	G3	G4
Any luminaire not ideally oriented*** with 1 to less than 2 mounting heights to any property line of concern	G0	G0	G1	G1	G2
Any luminaire not ideally oriented*** with 0.5 to 1 mounting heights to any property line of concern	G0	G0	G0	G1	G1
Any luminaire not ideally oriented*** with less than 0.5 mounting heights to any property line of concern	G0	G0	G0	G0	G1

*** Any luminaire that cannot be mounted with its backlight perpendicular to any property line within 2X the mounting heights of the luminaire location shall meet the reduced Allowed Glare Rating in Table C-3.

**“G” value follows the
Lighting Zone Value**

Some common luminaires...



250W HPS flat lens:
LZ3 and LZ4



150W HPS Sag Lens:
LZ4



No Photometric tests with
 90° - 180° measurements
taken, six manufacturers:
FAIL—All Zones

Similar Solutions

- Establish Lighting Zones
- Luminaire distribution = IES BUG Ratings
- **Lighting Level Management – Adaptive Standards**
- Spectral Distribution = Minimizing short wavelength light

IES RP-8 Criteria

Selected Street Classification	Selected Pedestrian Classification	Average Luminance (cd/m ²)*	Evening	Late Night
Major	High	1.2		
	Medium	0.9		
	Low	0.6		
Collector	High	0.8	0.8	
	Medium	0.6		
	Low	0.4		0.4
Minor	High	0.6		
	Medium	0.5		
	Low	0.3		

All Environmental Issues have similar solutions

- Establish Lighting Zones
- Luminaire distribution = IES BUG Ratings
- Lighting Level Management
- Spectral Distribution = Minimizing short wavelength light

Spectral Distribution and how it affects visibility

White light increases peripheral detection and renders colors better

Too much blue light could affect the environment



Spectral Distribution

Detection of Objects and People



Spectral Distribution

San Diego and Anchorage: Targets



- Visual target types also varied, with small targets placed at all locations
- Pedestrians (San Diego only) placed at intersections.

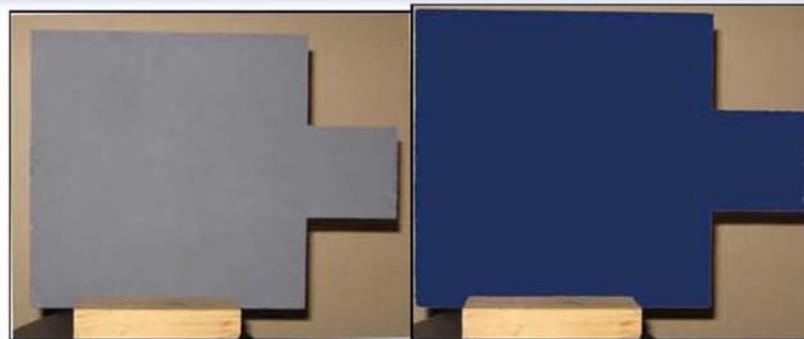


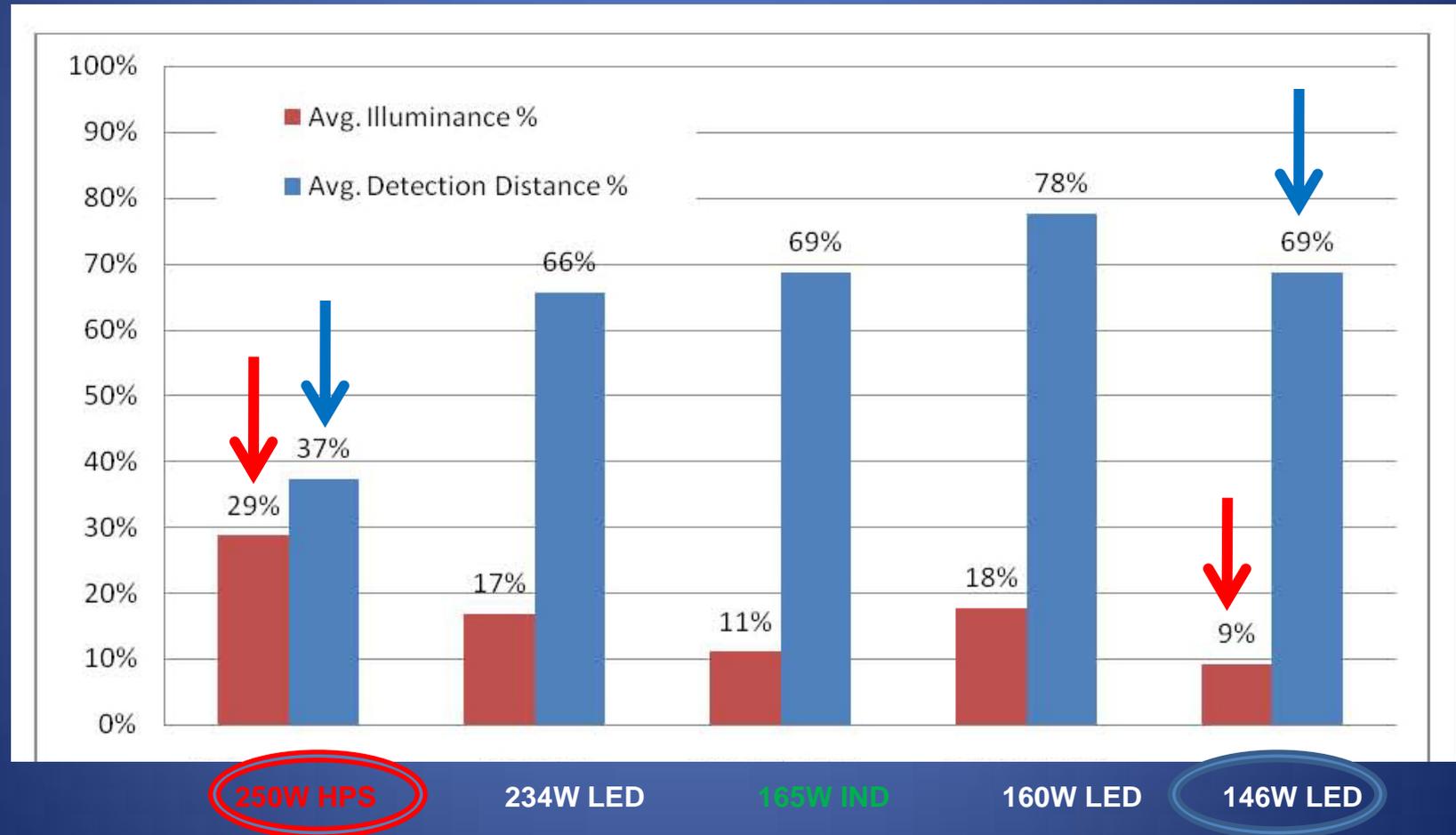
Figure 9: Example of Detection Targets along Experimental Route

Lighting Levels (100% and 50%)



Spectral Distribution and Adaptive Standards

Comparison to Anchorage: Average Illuminance vs. Detection Distance (as % of 400W HPS)



Effect of White Light

- S/P Ratio

- Ratio of scotopic to photopic luminous flux
- NO SUCH THING AS SCOTOPIC LUMENS!

CCT (K)	S/P Ratio
1500	0.03
2000	0.40
2500	0.75
3000	1.05
3500	1.33
3700	1.43
4000	1.56
4100	1.61
4300	1.69
4700	1.84
5000	1.93
5500	2.07
6000	2.16
6500	2.23

- Photopic Luminance

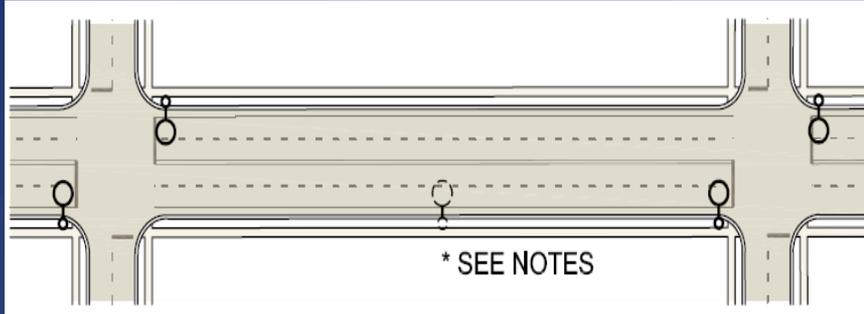
- Lighting calculation software
- Applied to each individual calculation point

Mesopic Lumen: CIE 191:2010

S/P	Photopic Luminance (cd/m ²)										
	0.01	0.03	0.1	0.3	0.5	1	1.5	2	3	5	
LPS~	0.25	-75%	-52%	-29%	-18%	-14%	-9%	-6%	-5%	-2%	0%
	0.45	-55%	-34%	-21%	-13%	-10%	-6%	-4%	-3%	-2%	0%
HPS~	0.65	-31%	-20%	-13%	-8%	-6%	-4%	-3%	-2%	-1%	0%
	0.85	-12%	-8%	-5%	-3%	-3%	-2%	-1%	-1%	0%	0%
WW LED~	1.05	4%	3%	2%	1%	1%	1%	0%	0%	0%	0%
	1.25	18%	13%	8%	5%	4%	3%	2%	1%	1%	0%
	1.45	32%	22%	15%	9%	7%	5%	3%	3%	1%	0%
	1.65	45%	32%	21%	13%	10%	7%	5%	4%	2%	0%
CW LED~	1.85	57%	40%	27%	17%	13%	9%	6%	5%	3%	0%
	2.05	69%	49%	32%	21%	16%	11%	8%	6%	3%	0%
	2.25	80%	57%	38%	24%	19%	12%	9%	7%	4%	0%
	2.45	91%	65%	43%	28%	22%	14%	10%	8%	4%	0%
	2.65	101%	73%	49%	31%	24%	16%	12%	9%	5%	0%

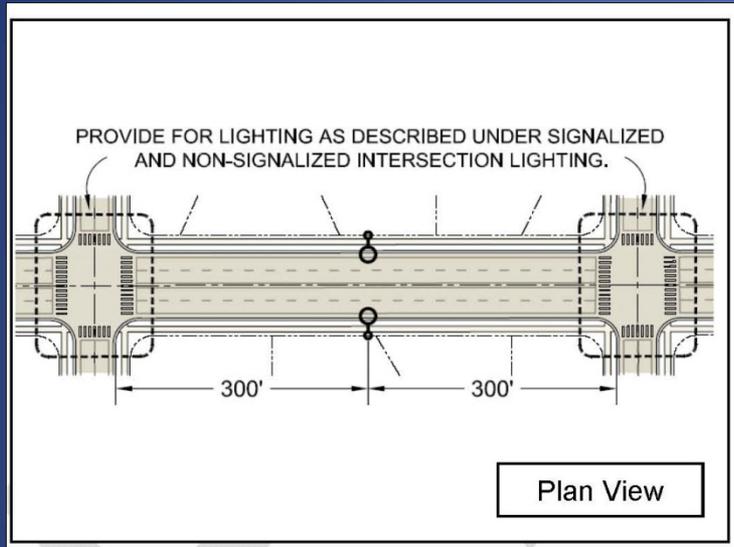
Spectral Distribution

Anchorage (collector)



- Replace 250w HPS with 170w LED (12500 lumens max)
- Color Temperature (CCT): 3500K-4300K
- Dim lighting by 50% during low ped activity
- **8 to 10 year payback**

San Diego (collector >52' wide)



- Replace 250w HPS with 150 - 165w Induction full cutoff
- Color Temperature (CCT): 3000K-4000K depending on proximity to Mount Palamar
- Future dimming
- **7 Year Simple Payback**



Results Summaries from all Cities

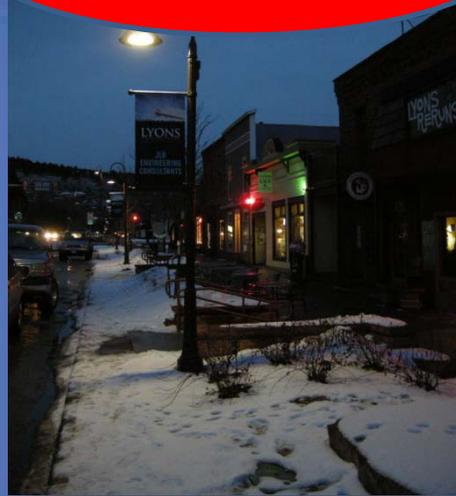
- Combining all of the results, these studies suggest that broad spectrum (white) light sources (3000K to 4000K) provide equivalent or better visual performance than the existing HPS luminaires.
- These alternative light sources provide equivalent performance at a lower roadway illuminance level.
- This suggests that the broad spectrum light sources do provide additional information in the visual scene and a higher potential performance

Exterior Lighting Design Issues

Luminance (STV)



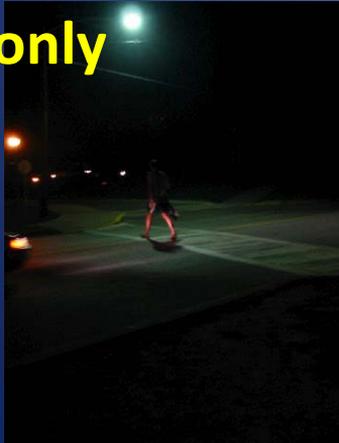
Spectral Effects



Adaptive Standards



Illuminance –
Intersections
only



Uniformity



Contrast



Glare



Adaptation



Guidelines

Night Visibility: **ILLUMINANCE**

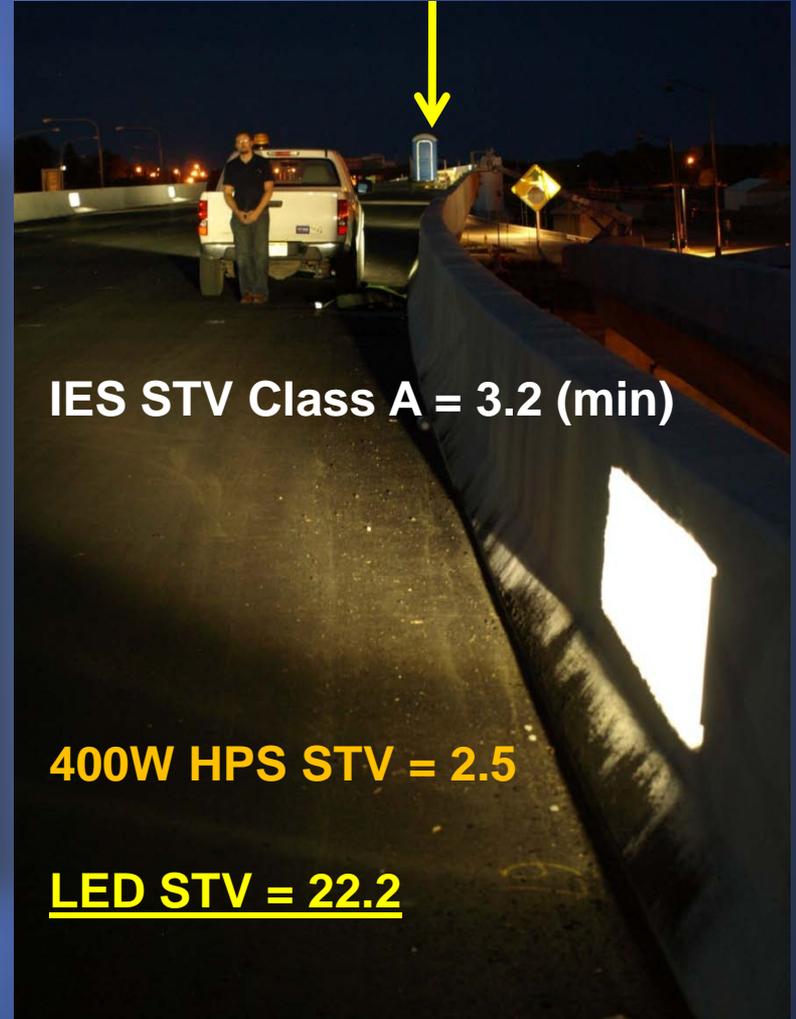
I-25 TRINIDAD, CO: Viaduct Replacement



75 – 90% less energy ... and minimizing Light Trespass



Better Detection?



IES STV Class A = 3.2 (min)

400W HPS STV = 2.5

LED STV = 22.2

LED Streetlights and the Environmental - Future LED Lighting -

Puragra (Raja) GuhaThakurta

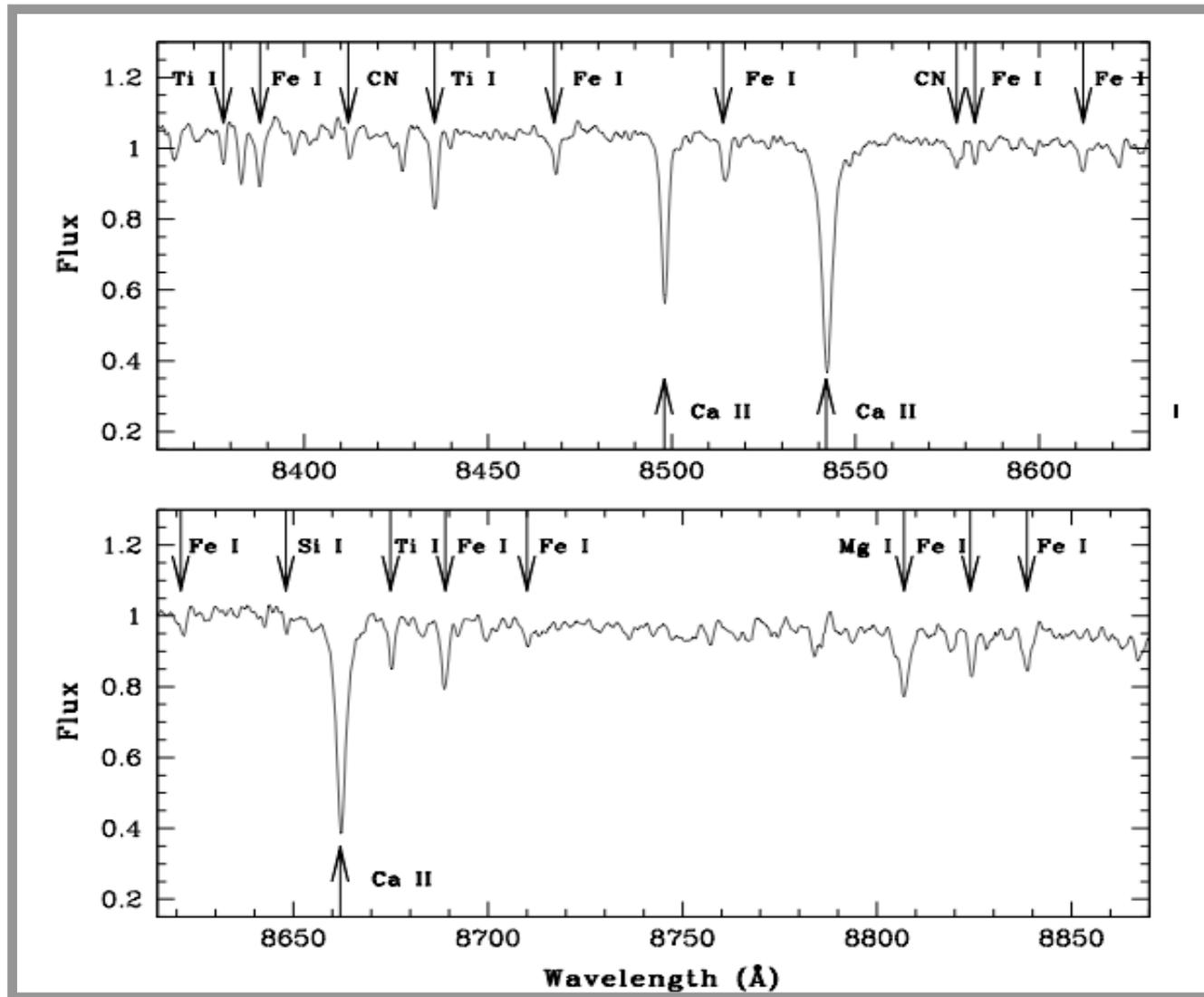
Astronomer / Professor, UCO/Lick Observatory
University of California
Office phone: +1 831 459 5169
E-mail: raja@ucolick.org

Can LED streetlights of the future adequately serve the needs of:

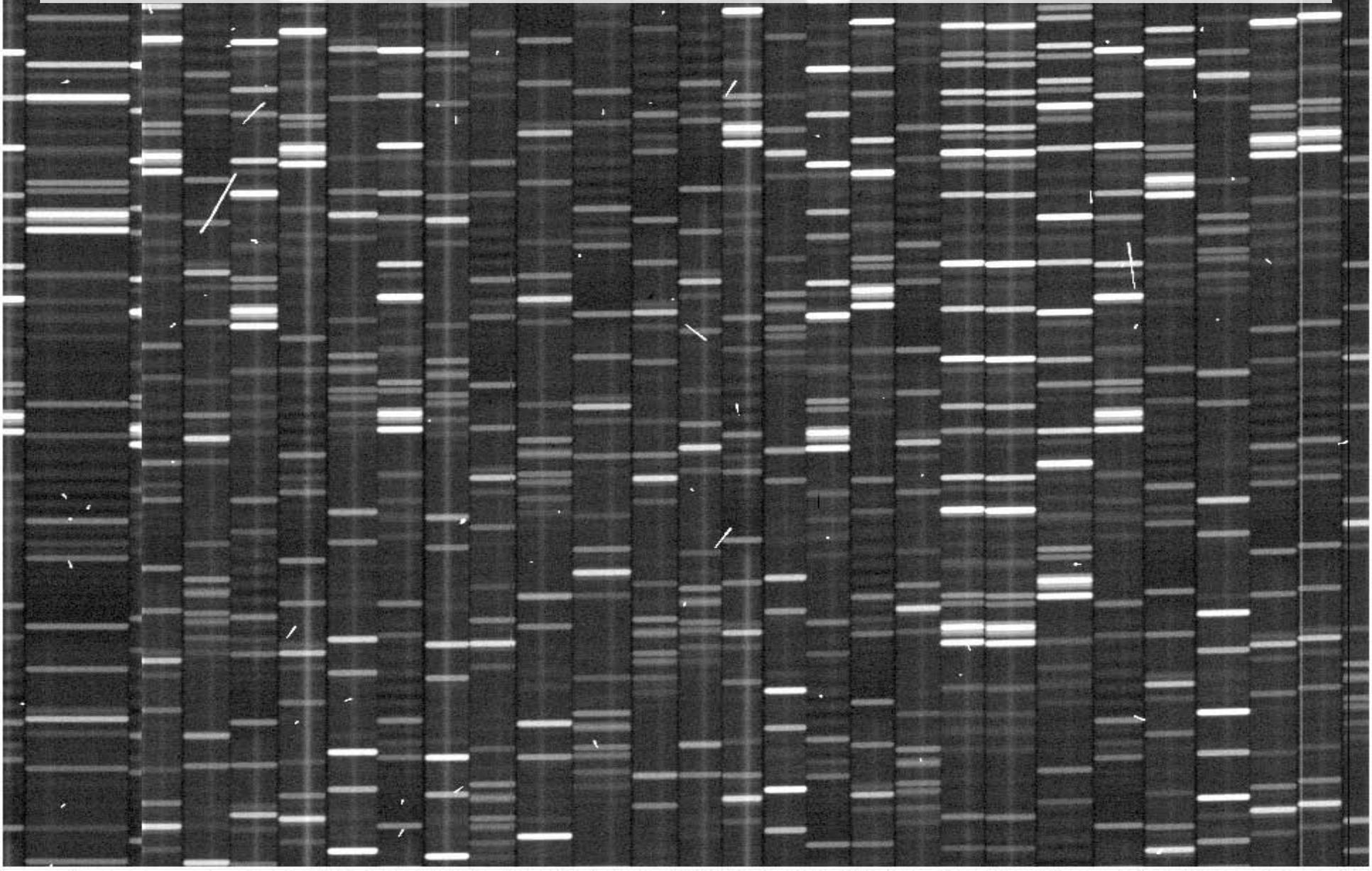
- A. everyday citizens?
- B. without impeding what is arguably mankind's deepest scientific quest and exploration?
- C. while preserving the pristine nature of the Earth's environment?



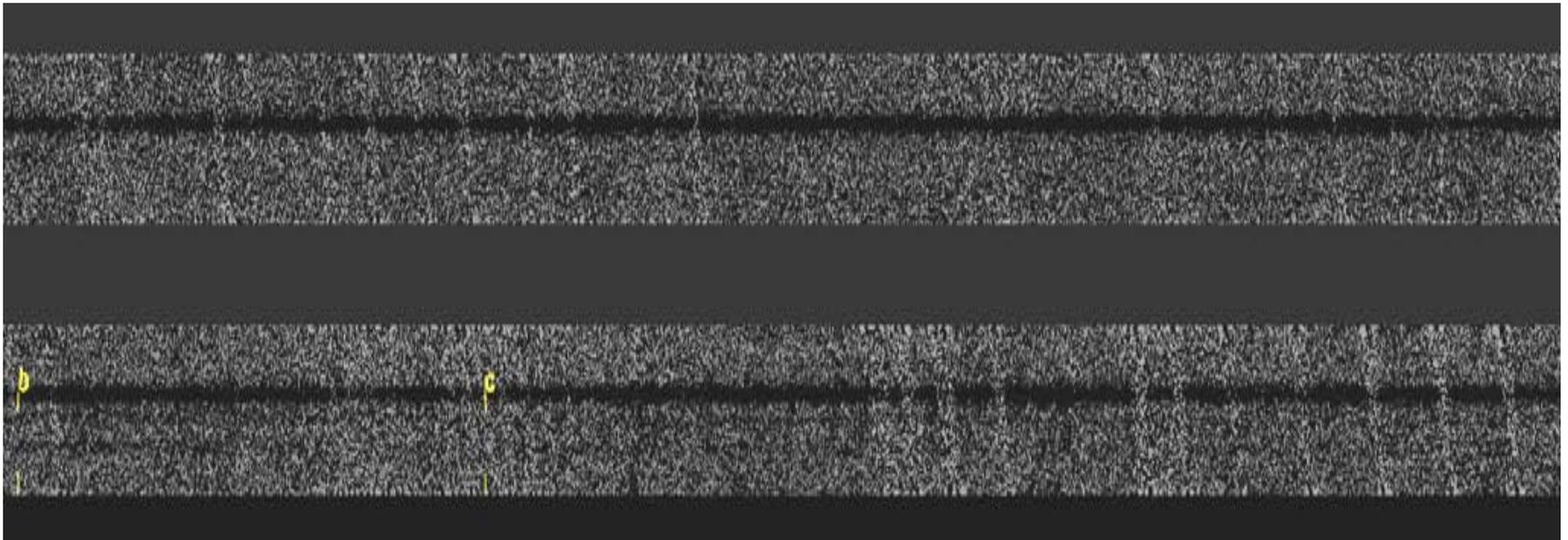
To astronomers, a spectrum is worth a thousand pictures



The earth's atmosphere, even at the darkest of sites, glows at certain very specific wavelengths

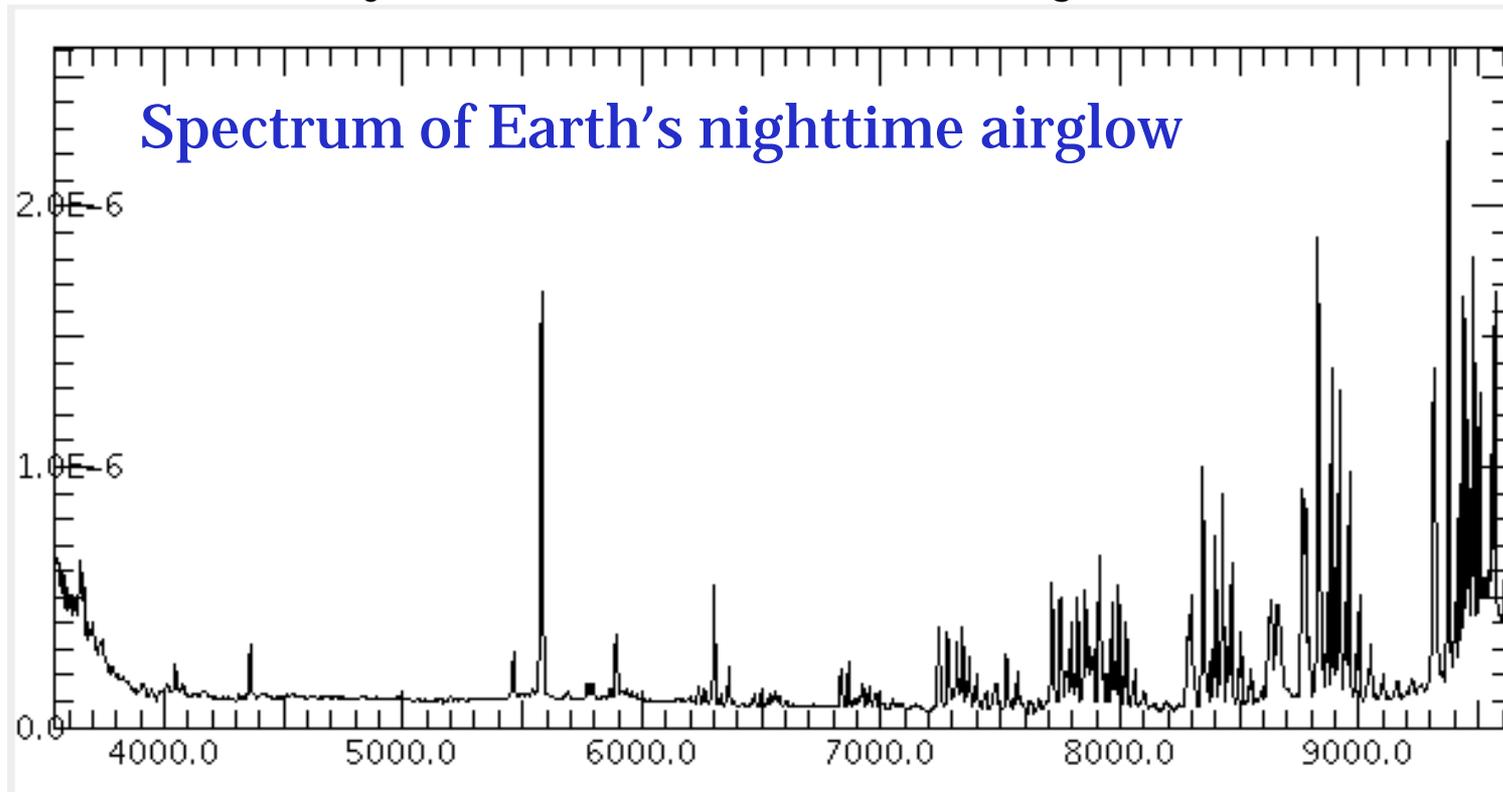


Astronomers use a technique known as “sky subtraction” to remove the glow of the night sky



However, there is inevitably extra noise at the wavelengths corresponding to the night sky’s “emission lines” and this becomes the limiting factor in the extraction of useful astronomical data

If you can't beat Nature, join it!



Can we design LEDs that only emit light over a very narrow range of wavelengths (tenth of a nanometer) and can we design a set of RGB LEDs that only emit light at the precise wavelengths of our choosing?

The LED streetlight of the future?

- A. Mix LED lights of different but very specific colors in the correct proportion to produce white light (or, for that matter, light of any color)
- B. The adverse effect of streetlights on astronomical observations would be limited to very specific wavelengths, ones that are already affected by the Earth's nighttime airglow
- C. The spectrum of man-made lighting from the nighttime Earth (as seen from outer space, for example) would be remarkably similar to its natural airglow

LED Streetlights and the Environment - Outdoor LED Lighting -

Dale Kane

Global Outdoor Segment Marketing Manager

Philips Lumileds

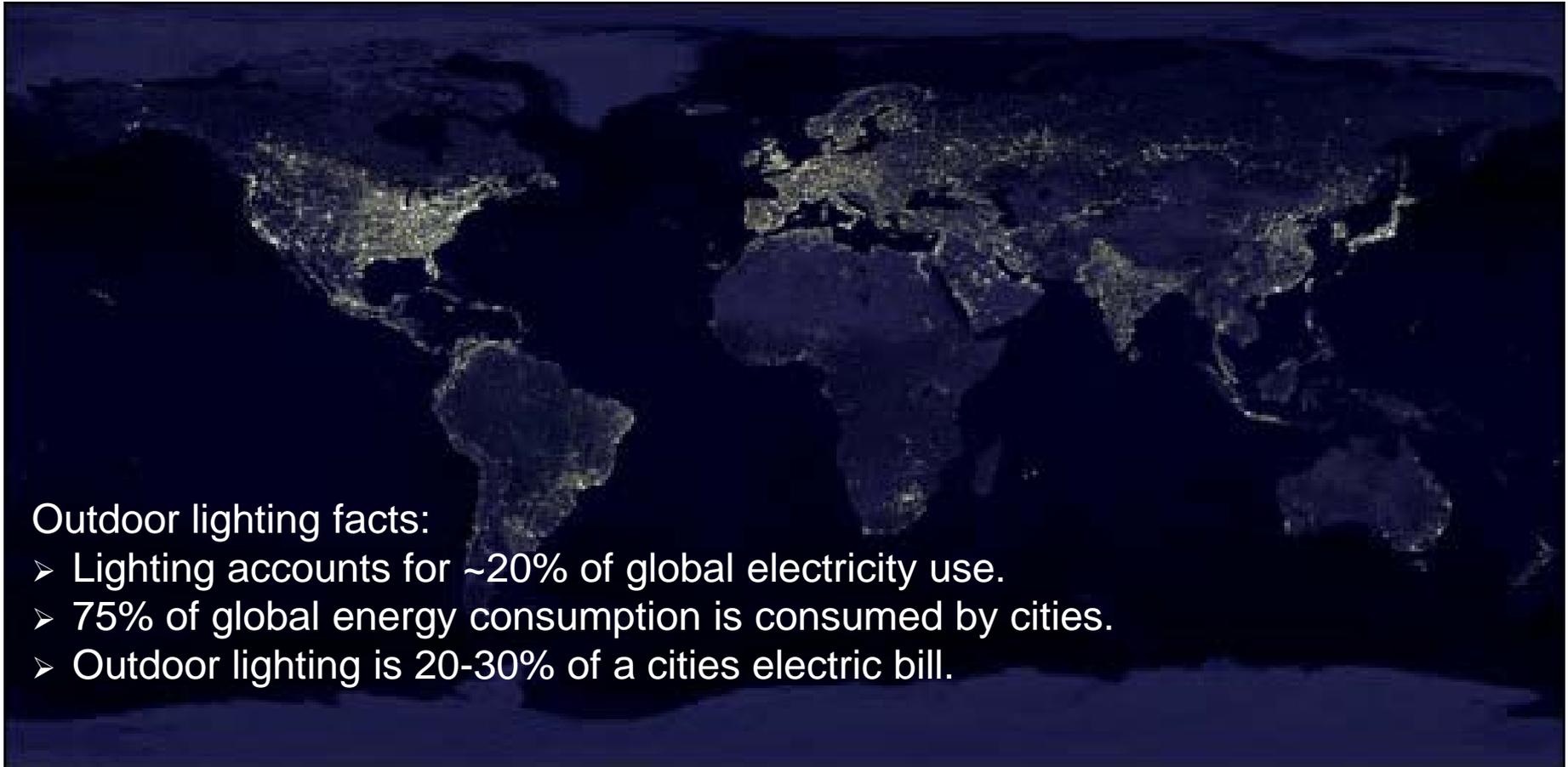
370 West Trimble Road

San Jose, CA 94114

408-904-3851

Dale.Kane@Philips.com

Outdoor Lighting



Outdoor lighting facts:

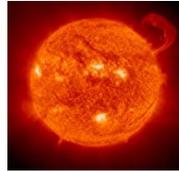
- Lighting accounts for ~20% of global electricity use.
- 75% of global energy consumption is consumed by cities.
- Outdoor lighting is 20-30% of a cities electric bill.

Wide variety of current products



Evolution of Lighting

- Nuclear reaction



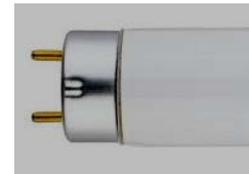
- Chemical reaction (combustion)



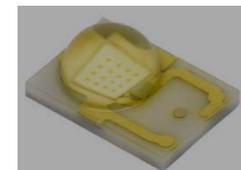
- Resistive heating (incandescent)



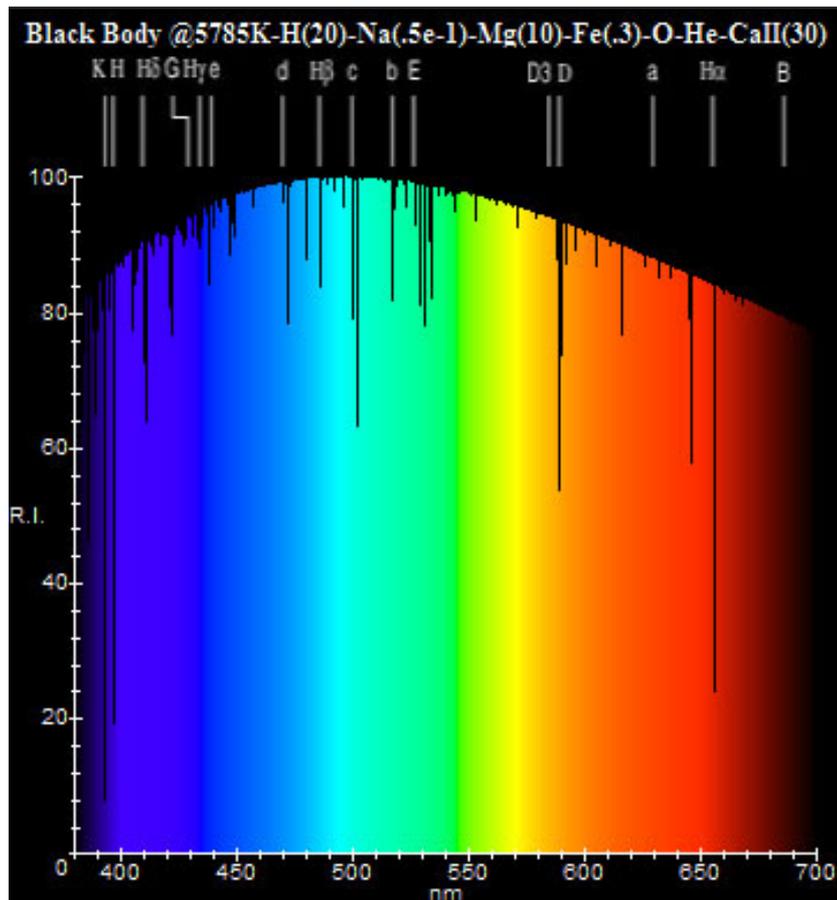
- Gas discharge (fluorescent, high pressure sodium lamp)



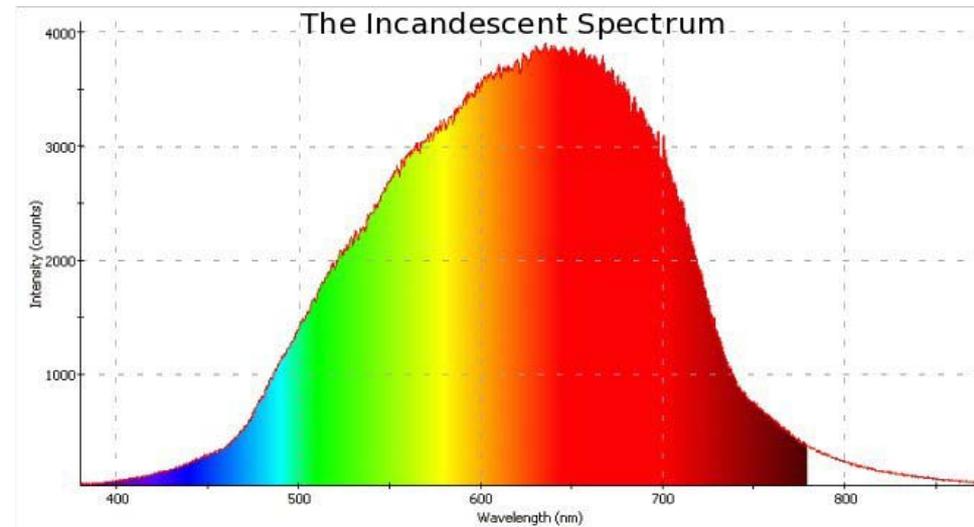
- Electroluminescence (light emitting diodes, LED)



Spectrum of Sunlight

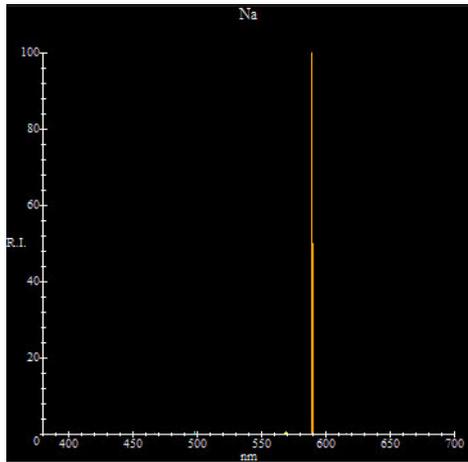


Traditional Light Bulbs

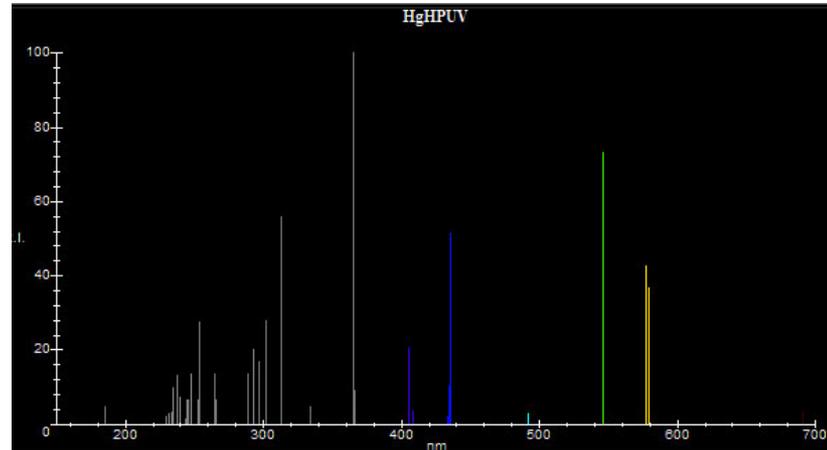


Traditional Streetlight Sources

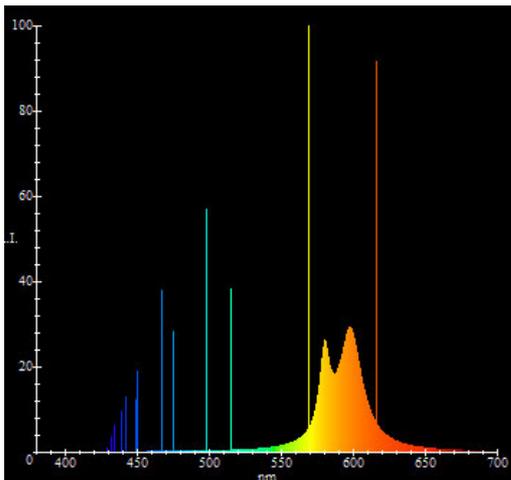
LPS (CRI ~5)



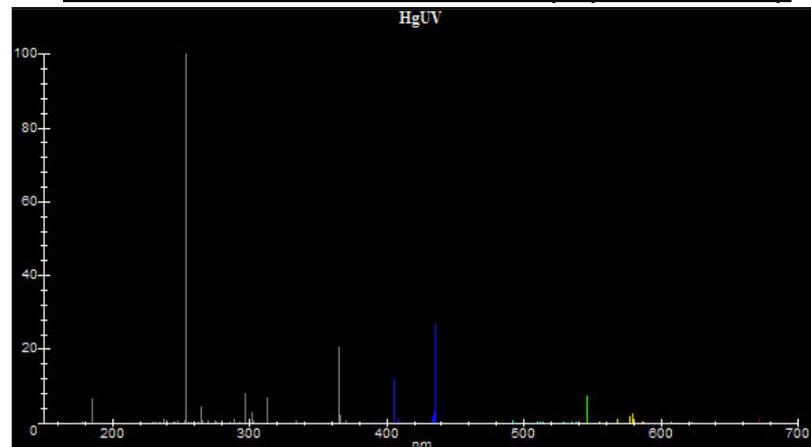
High Pressure Mercury Vapor (CRI 17-49)



HPS (CRI ~24)



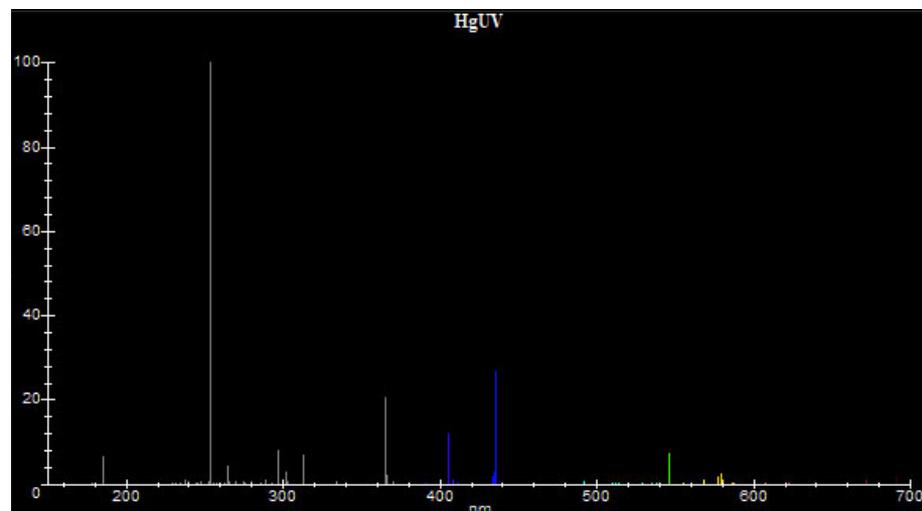
Low Pressure Mercury Vapor (aka
Fluorescent / Induction) (CRI 50+)



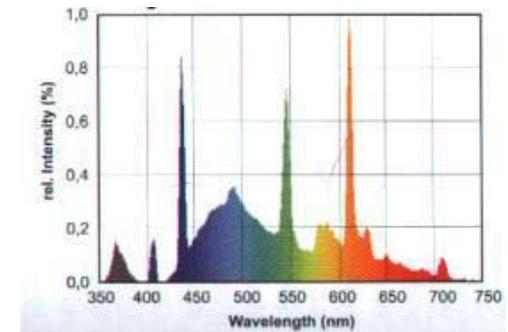
Traditional Streetlight Sources

- Spectrum of the source light is set by the elemental composition of the gas (Mercury, Sodium etc...)
- Phosphors shift the light to the visible spectrum to “white” light

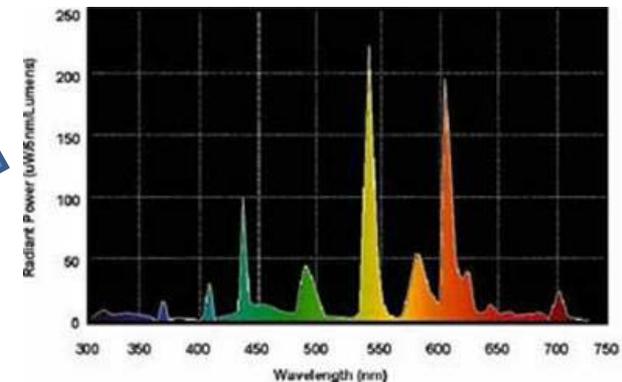
Low Pressure Mercury Vapor (Fluorescent)



Phosphor
Converted



Phosphor
Converted

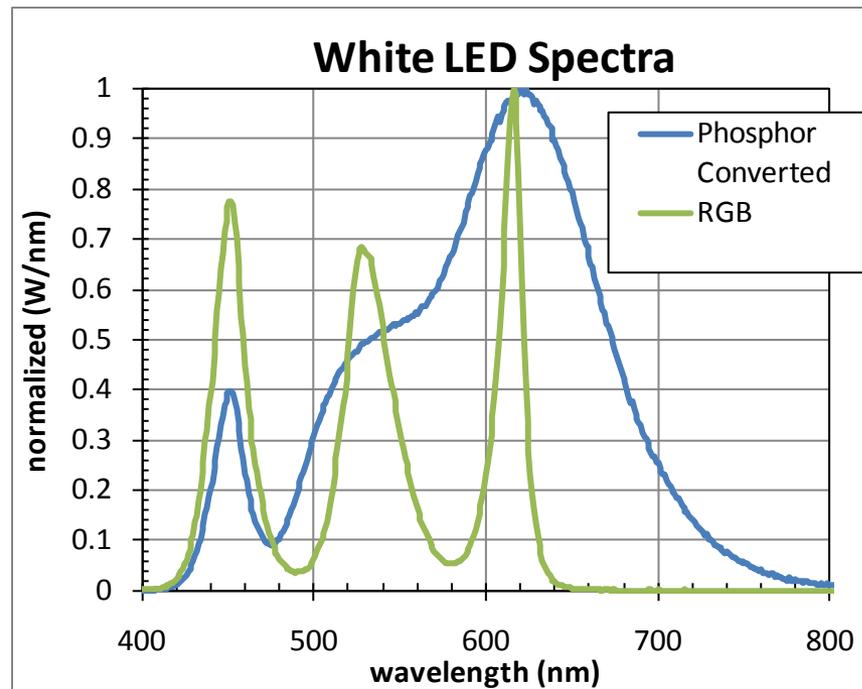


LEDs allow for control of source light

Color	Wavelength [nm]	Semiconductor material
Red	$610 < \lambda < 760$	Aluminium gallium arsenide (AlGaAs) Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Orange	$590 < \lambda < 610$	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Yellow	$570 < \lambda < 590$	Gallium arsenide phosphide (GaAsP) Aluminium gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Green	$500 < \lambda < 570$	Indium gallium nitride (InGaN) / Gallium(III) nitride (GaN) Gallium(III) phosphide (GaP) Aluminium gallium indium phosphide (AlGaInP) Aluminium gallium phosphide (AlGaP)
Blue	$450 < \lambda < 500$	Zinc selenide (ZnSe) Indium gallium nitride (InGaN) Silicon carbide (SiC) as substrate Silicon (Si) as substrate – (under development)
Violet	$400 < \lambda < 450$	Indium gallium nitride (InGaN)

Application Specific Spectral Control

- With LEDs it is possible to control both the spectrum of the source and the phosphors used to convert the light to the desired CRI and color temperature



Roadway



Application Specific LEDs

Required CCT

4000-5700K

Required CRI

60-70 min

Under Canopy (petroleum)



Required CCT

4000-5000K

Required CRI

70-80 min

City Centers



Required CCT

3000-4000K

Required CRI

60-80 min

Architectural



Requirements

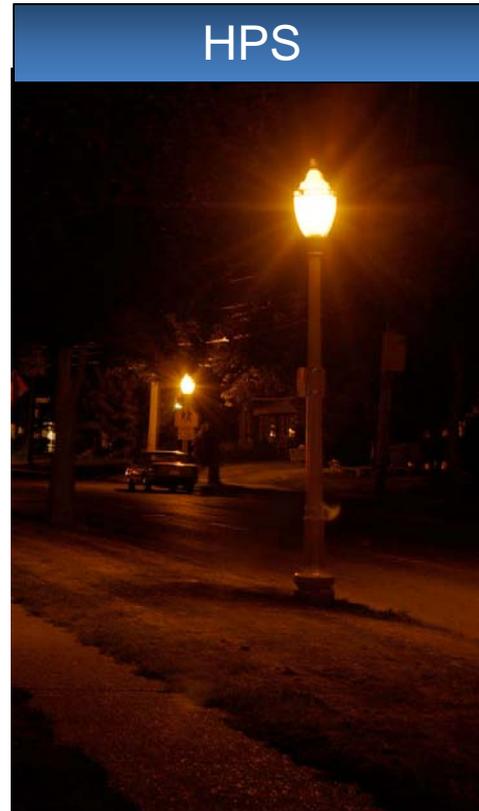
- White
- Tunable White
- Colored
- Dynamic Color

- Green
- Cyan
- Blue
- Royal-Blue (specified in radiometric power (mW))
- Deep Red (specified in radiometric power (mW))
- Red
- Red-Orange
- Amber

Top 5 Environmental Benefits of LEDs

#1 - LEDs provide a higher quality of light

Lansing Michigan		
	HPS 70W	LUXEON LED
Watts	85	55
KWh/yr	357	185
Lumens	4400	3600
CRI	25	70
Mercury	Yes	No
Lifetime (yrs)	4	15+
Payback		< 4 years



LUXEON Rebel was 90 lumen parts

Courtesy: Midwest Circuits

#2 - LED's provide large energy & CO₂ savings



- LEDs provide a 77% energy savings over traditional HPS.

IntenCity Lighting Solution				
Area	Fixtures Used	Watts	Quantity	Total Watts
Drive Isles	SL-50 LED Garage Light	80 watts	325	26,000
Stairwell & Exits	WP-14 LED Wall Packs	30 watts	59	1,770
Roof	SL-50 2x LED Parking Lot Lights	100 watts	16	1,600
Perimeter	WP-45 LED Wall Packs	80 watts	17	1,360
Electric Cost Per Year:		\$22,958	Total Watts:	30,730

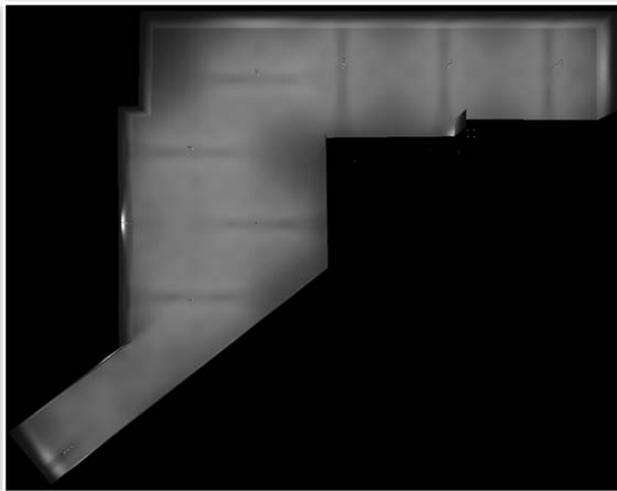
Traditional Metal Halide Fixture Option				
Area	Fixtures Used	Watts	Quantity	Total Watts
Drive Isles	MH Garage Lights*	165 watts	660	108,900
Stairwell & Exits	MH Wall Packs*	110 watts	59	6,490
Roof	MH Parking Lot Lights*	275 watts	16	4,400
Perimeter	MH Wall Packs*	440 watts	17	7,480
Electric Cost Per Year:		\$98,392	Total Watts:	127,270

#3 – High utilization of produced light

- Properly specified light on the ground and allowed uniformity provides a superior specification vs. raw lumens from a fixture.
- Below, properly specified LED's result in a 46% energy savings while providing a higher minimum illuminance and superior uniformity

Why a Performance Spec? LED Example

U.S. DEPARTMENT OF
ENERGY | Energy Efficiency &
Renewable Energy



Source: Computer Rendering

Lighting System:
217 W LED fixture

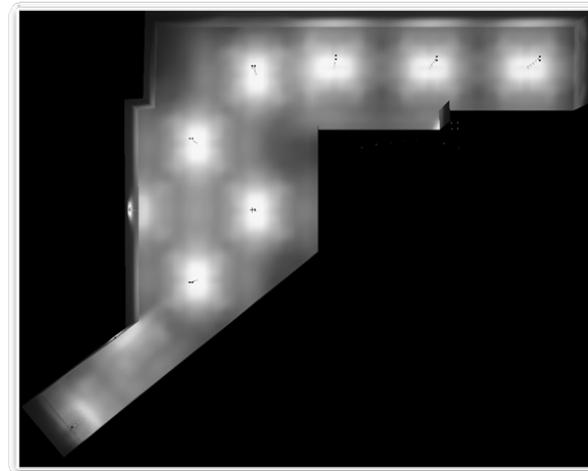
Illuminance Data:

Average: 2.02 fc
Max: 3.5 fc
Min: 0.3
Max: Min: 11.67

Power Density:
0.06 W/sf

Why a Performance Spec? Pulse-Start Metal Halide Example

U.S. DEPARTMENT OF
ENERGY | Energy Efficiency &
Renewable Energy



Source: Computer Rendering

Lighting System:
400 W PSMH fixture

Illuminance Data:
Average: 4.85 fc
Max: 15 fc
Min: 0.2
Max: Min: 75

Power Density:
0.10 W/sf

#4 - LEDs reduce light pollution



The “black” skyline of New York...

Ecology

(Disruption of EcoSystems
Recent links to air quality)

Comfort at home

(Linking to consequences of health)

Darker Sky

Safety on the street

1 Direct upward light

8 Sky glow

5 Light trespass

9 Spill light

2 Dwelling

3 Glare

3 Glare

11 Useful light

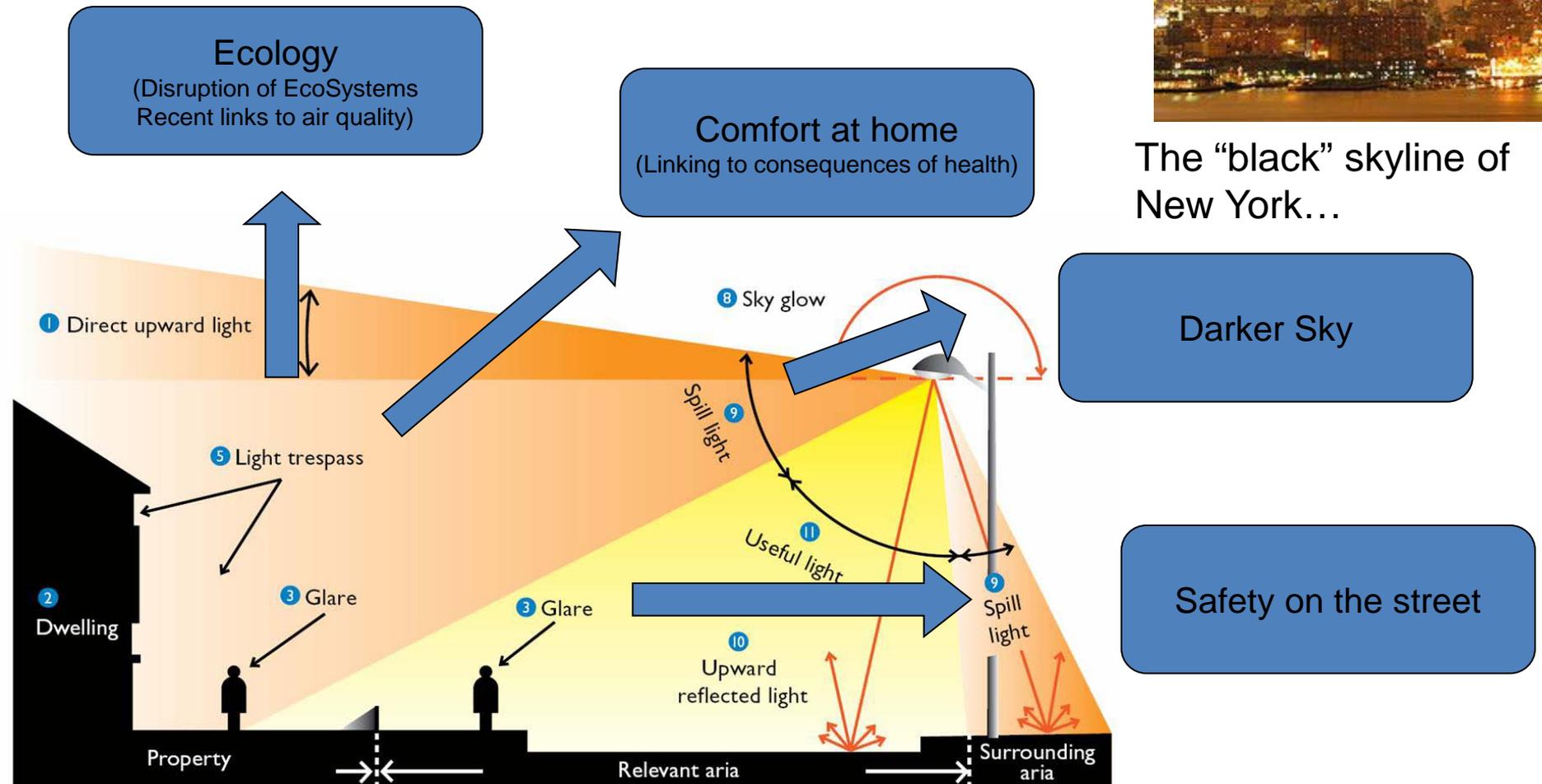
9 Spill light

10 Upward reflected light

Property

Relevant aria

Surrounding aria



#5 - LEDs are long lasting and environmental friendly

- Our LEDs are Lead-free, Mercury-free and RoHS Compliant and do not contain
 - toxic heavy metals e.g. mercury (unlike fluorescent, HID)
 - persistent organic pollutants (POPs)
 - or off-gas any volatile organics (VOCs)

- We meet or exceeds all relevant environmental laws and regulations including:
 - Montreal Protocol for the elimination of ozone-depleting compounds
 - RoHS: Regulation of Hazardous Substances
 - Federal, State, and Local regulations (e.g.)
 - Electronic Industry Code of Conduct (EICC)



Questions

