



**VS**





## CCFL (Cold Cathode Fluorescence Lamp)

- Edge-Light
- Direct Backlight

## LED (Lighting Emitting Diode)

- Edge-Light
- Direct Backlight
- White or RGB

## EL (Electro Luminance)

- Direct Backlight

# Objectives of the Course








- White LED Technology
  - Types of white LEDs
- Design Advantages of the Technology
  - Life
  - Efficiency
- Design Considerations
  - Color matching
  - Heat dissipation
  - Cost
- Range of Products Available Today

# White Through History



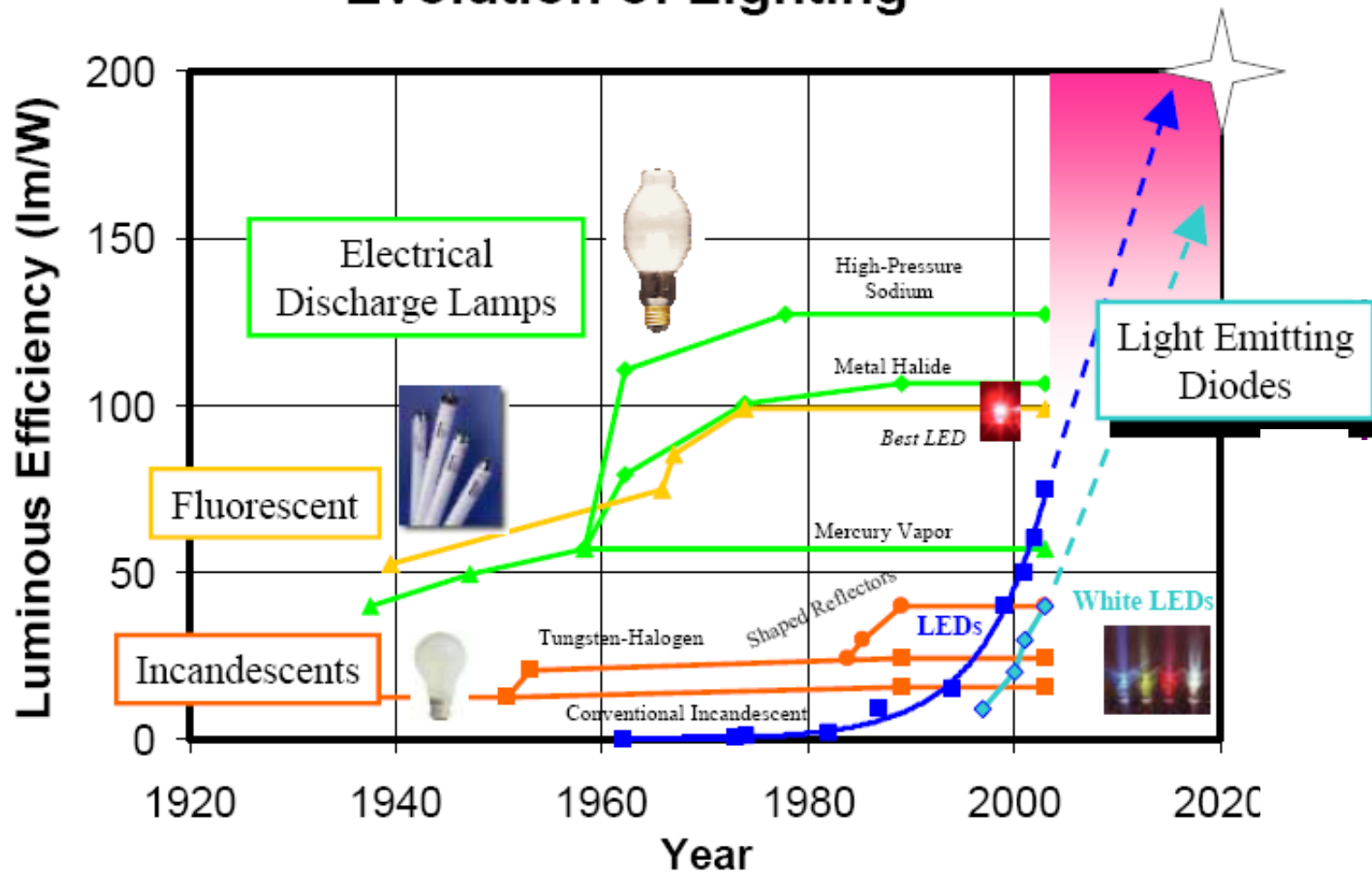
Progress in lighting

Luminous Efficiency (lm/W)				
Candle 1400's	Incandescent 1800's	Flourescent 1920's	HID 1950's	LED 2000's
				
1	10-15	70-100	80-120	80-100

# Progression of White Lighting



## Evolution of Lighting



## Specifying LEDs (in general)

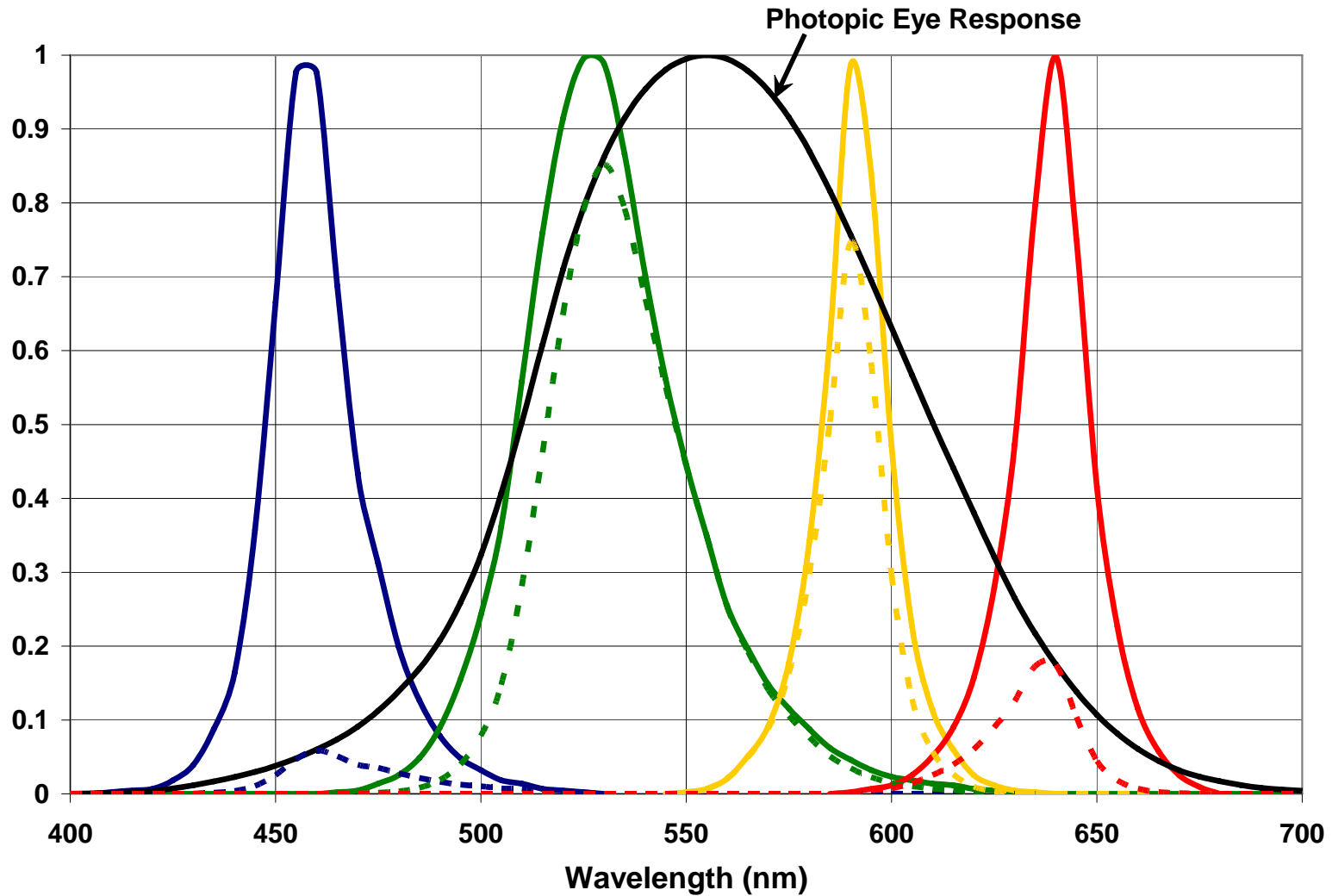


- Type (3mm, 5mm, High Flux, etc.)
- R-G-B with different LED's
- White LED's

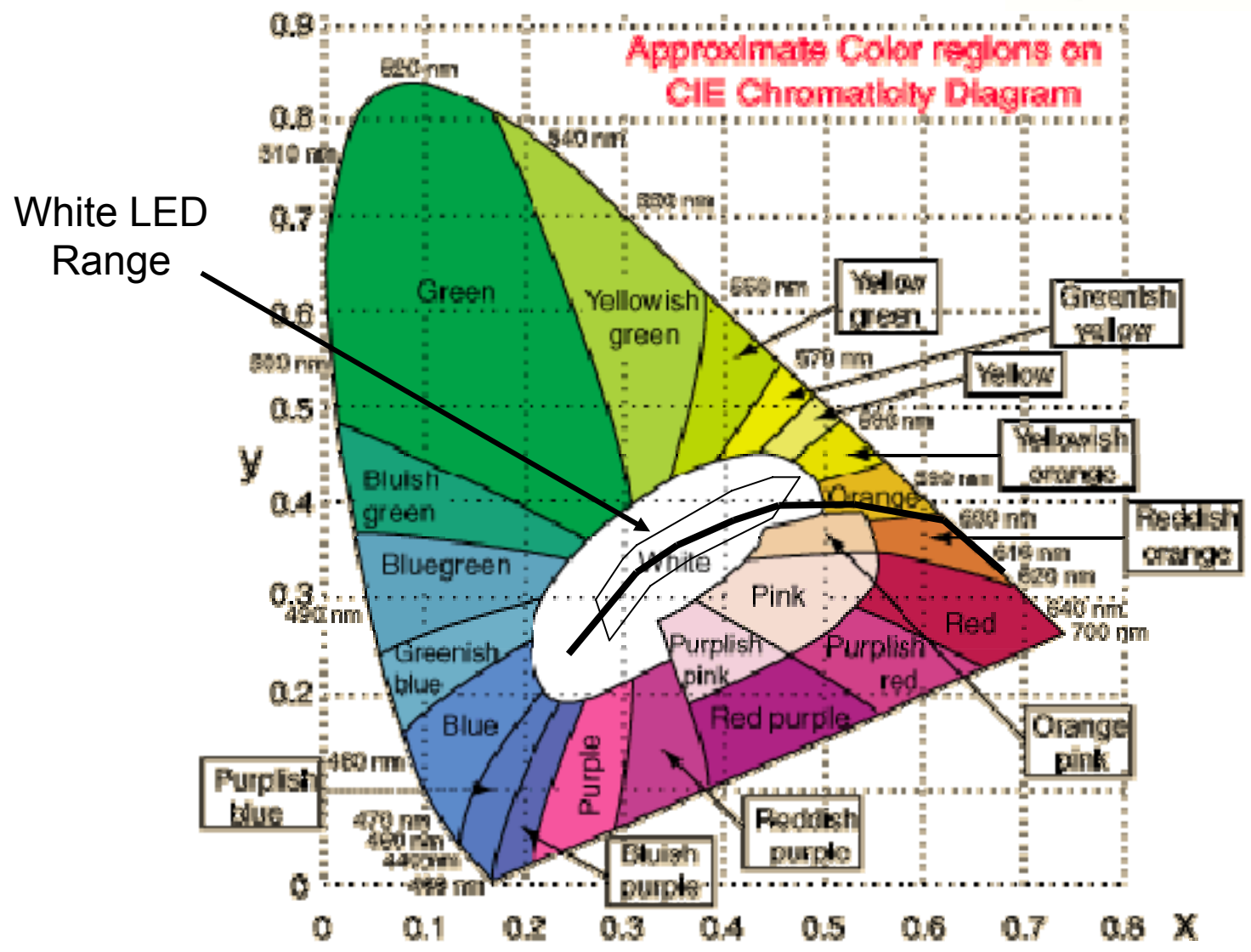


# Definitions—Flux

## Radiometric Flux to Luminous Flux



# Definitions - Color





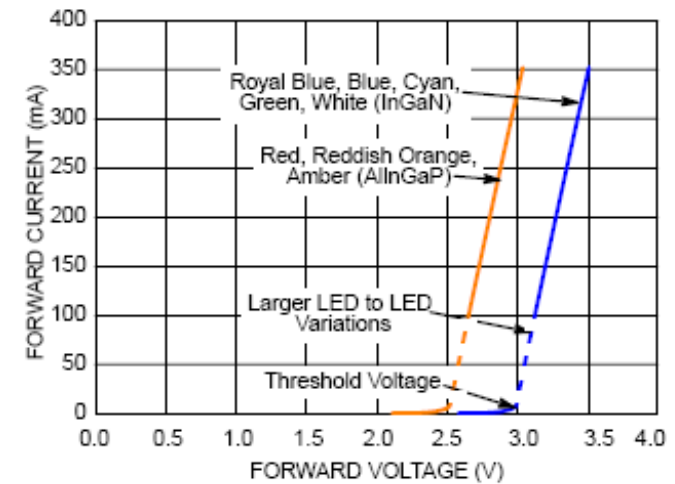
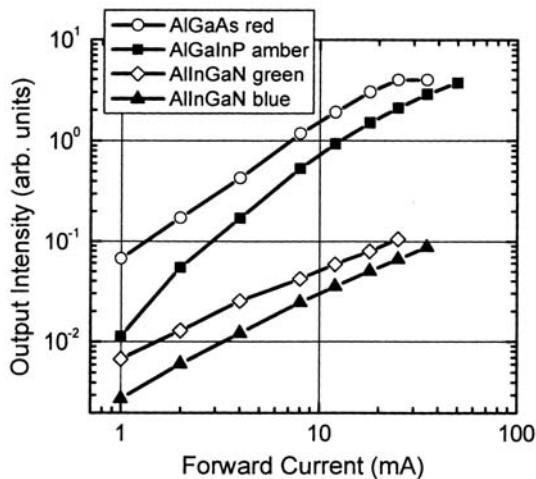
# Definitions – Forward Voltage



- Forward Voltage  $V_f$  is roughly equal to the bandgap energy of the LED semiconductor divided by the elementary charge

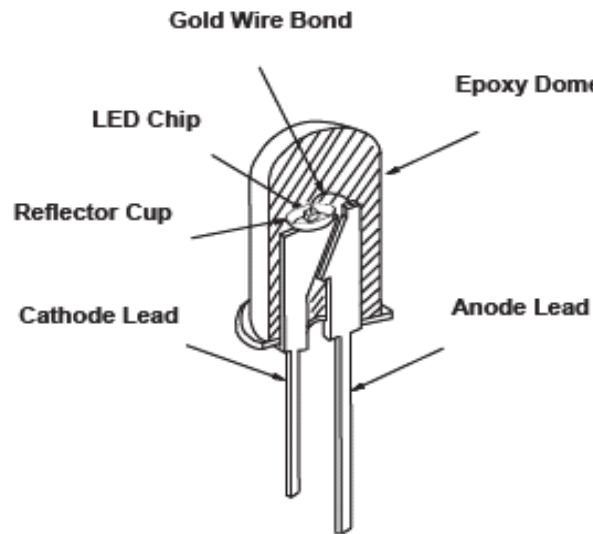
$$V_f = E_g / q$$

where  $q = 1.6 \times 10^{-19}$  coulombs



- Output Intensity of typical high brightness LEDs is dependent on the Forward Current  $I_f$

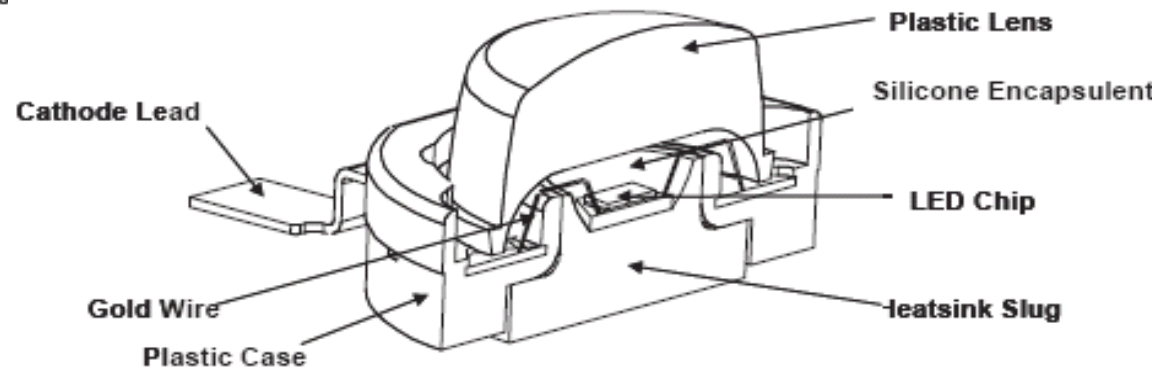
# Construction Difference (5mm versus High Flux LEDs)



**Typical construction  
for a 5mm LED**

Typical Flux = 3 lm

Number of LEDs to equal the  
output of a 60W incandescent  
light bulb = 200



**Typical  
construction for a  
High Flux LED**

Typical Flux > 30 lm

Number of LEDs to equal the  
output of a 60W incandescent  
light bulb < 20



AllnGaP  
Red, Red-Orange  
Yellow

AllnGaN  
Green, Blue,  
White

Group XIII	Group XIV	Group XV
5 <b>B</b> Boron 10.811	6 <b>C</b> Carbon 12.0107	7 <b>N</b> Nitrogen 14.006
13 <b>Al</b> Aluminum 26.981	14 <b>Si</b> Silicon 28.0955	15 <b>P</b> Phosphorus 30.973
31 <b>Ga</b> Gallium 69.723	32 <b>Ge</b> Germanium 72.61	33 <b>As</b> Arsenic 74.921
49 <b>In</b> Indium 114.818	50 <b>Sn</b> Tin 118.710	51 <b>Sb</b> Antimony 121.760

Substrates  
Silicon Carbide (SiC)  
Sapphire (Al<sub>2</sub>O<sub>3</sub>)

Base Elements
P-Type Dopants
N-Type Dopants



# How do you make LEDs?

## Lens Materials



### 3 mm and 5 mm

- **Epoxy lens**
  - Bad expansion coefficient (stresses bond wire)
  - Yellows
  - Degradation blue/UV

### HIGH FLUX

- **COC, other hard plastic lens with silicone gel**
  - Plastic with silicone gel
  - Not reflow solderable
- **Silicone polymer lens with silicone gel**
  - Robust for reflow, lead free temperature 260C
  - Better moisture handling
  - Susceptible to dirt and scratches
- **Glass lens with silicone gel**
  - More robust
  - Higher cost

# How do you make LEDs?

## Substrate Materials

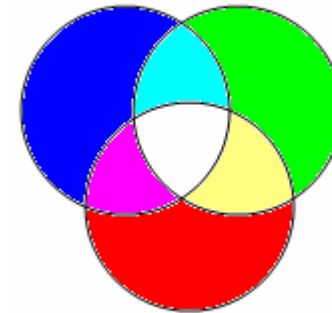
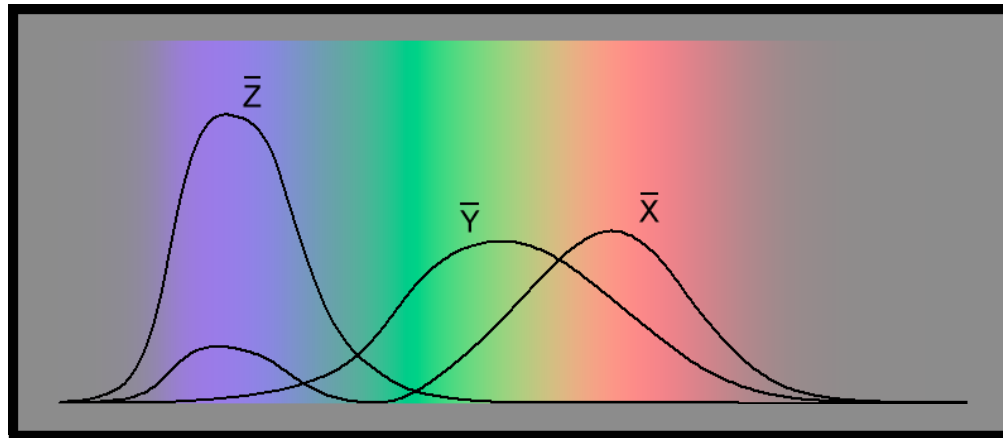


- **Sapphire ( $\text{Al}_2\text{O}_3$ )**
  - Lower cost (estimated at \$3/cm<sup>2</sup>)
  - More transparent (more light output)
  - Low thermal conductivity (40 W/m/K)
- **Silicon Carbide (SiC)**
  - Higher cost (estimated at \$12/cm<sup>2</sup>)
  - Better ESD protection
  - High thermal conductivity (350-490 W/m/K)

# How do you make a White LED?



RGB Method



Mixing light from red, green and blue LEDs (either discrete or combined in one package) can produce white light



# How do you make a White LED?



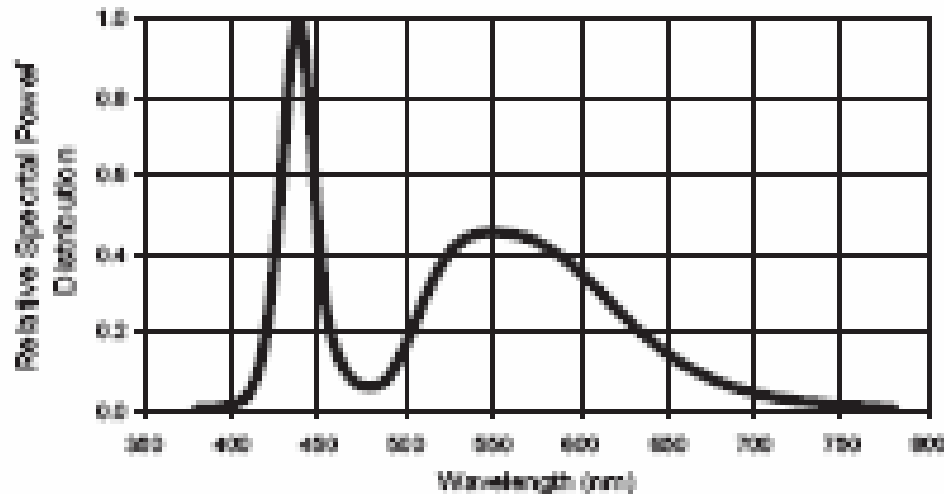
## Visible LED Pump + Phosphor Method

Blue LED + YAG **Cool White**

Blue LED + YAG + Other phosphor (red, green, etc.) **Warm White**

## UV LED Pump + Phosphor Method

UV LED + Red phosphor + Green phosphor + Blue phosphor



Luxeon K2

# How do you make a White LED?



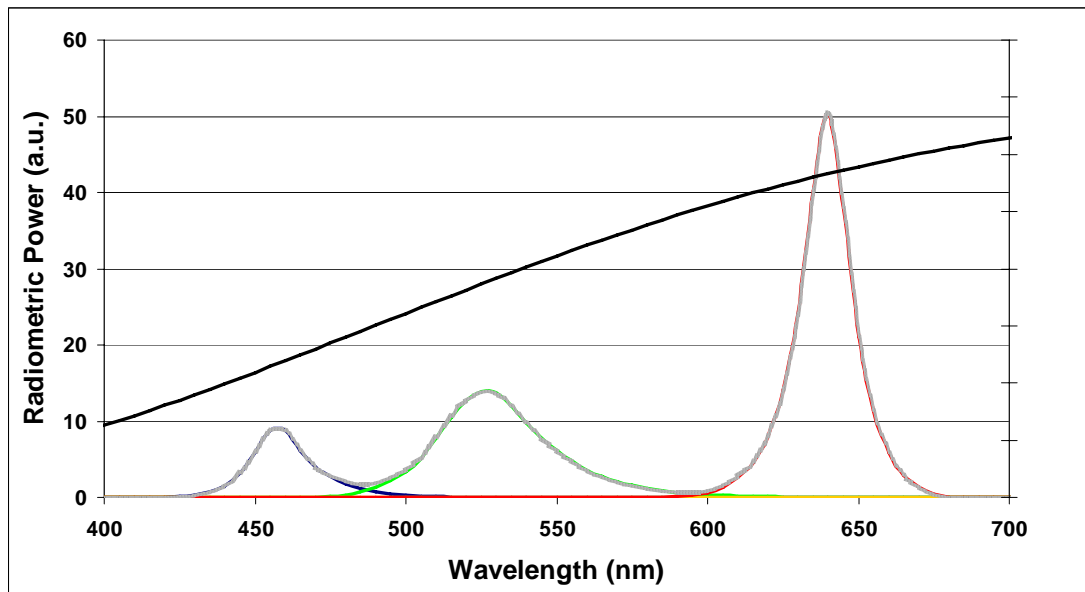
(Blue + Phosphor) VS (Red + Green + Blue)

Warm White (3500K)

**Blue + Phosphor**

100	lumens
34	lumens/watt
2.92	watts

Blue	Green	Red	Total
2.3	66.7	30.7	100 lumens
13.4	38.9	29.9	n/a lumens/watt
0.17	1.71	1.03	2.91 watts

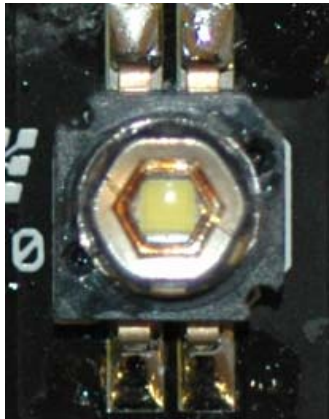


# How do you make a White LED?

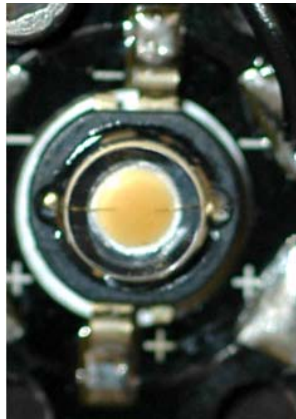


## Phosphor Deposition Examples

Lumileds



Lumileds



Seoul Semiconductor



Osram



Cree



Nichia





# How do you make a White LED?

## Which method is better for making white?

	RGB	Blue + Phosphor	UV + Phosphor
Advantages	<ul style="list-style-type: none"> <li>• Color can be changed dynamically</li> <li>• As a luminance source, millions of colors can be produced</li> <li>• Highest theoretical luminous efficiency of all three methods</li> <li>• No UV output</li> </ul>	<ul style="list-style-type: none"> <li>• High theoretical luminous efficiency</li> <li>• Can provide color temperatures between 3200 K (warm white) and 10,000 K (cool white)</li> <li>• No UV output</li> </ul>	<ul style="list-style-type: none"> <li>• Good color uniformity</li> <li>• Simple driver electronics</li> <li>• Potential for limited tint variation</li> <li>• Eliminates the pump color variation; only phosphor variation</li> </ul>
Disadvantages	<ul style="list-style-type: none"> <li>• Color can shift due to aging and temperature</li> <li>• Requires more sophisticated electronics</li> <li>• Poor color rendition</li> <li>• Fixture efficiency drop caused by color mixing</li> </ul>	<ul style="list-style-type: none"> <li>• Potential to create variations in tint</li> <li>• Must be controlled using optics and binning</li> </ul>	<ul style="list-style-type: none"> <li>• Lowest luminous efficiency</li> <li>• Shorter life</li> <li>• Clouding of the epoxy (UV packaging problems)</li> <li>• New phosphors necessary</li> </ul>

# How long do light sources last?



Time to change the lightbulb!

- The sun >4.5 billion years (so far)
- Candle <12 hours
- Oil Lamp <24 hours
- Incandescent (Bulb) 1k-1.5k hours
- Fluorescent (CCFL) 25k-60k hours
- Mercury Vapor 10k-20k hours
- Sodium Vapor 24k hours
- Metal Halide 20k-30k hours
- 5mm LEDs <10k hours
- High Flux LEDs >20k hours

What is End of Life  
for some  
illumination  
sources?

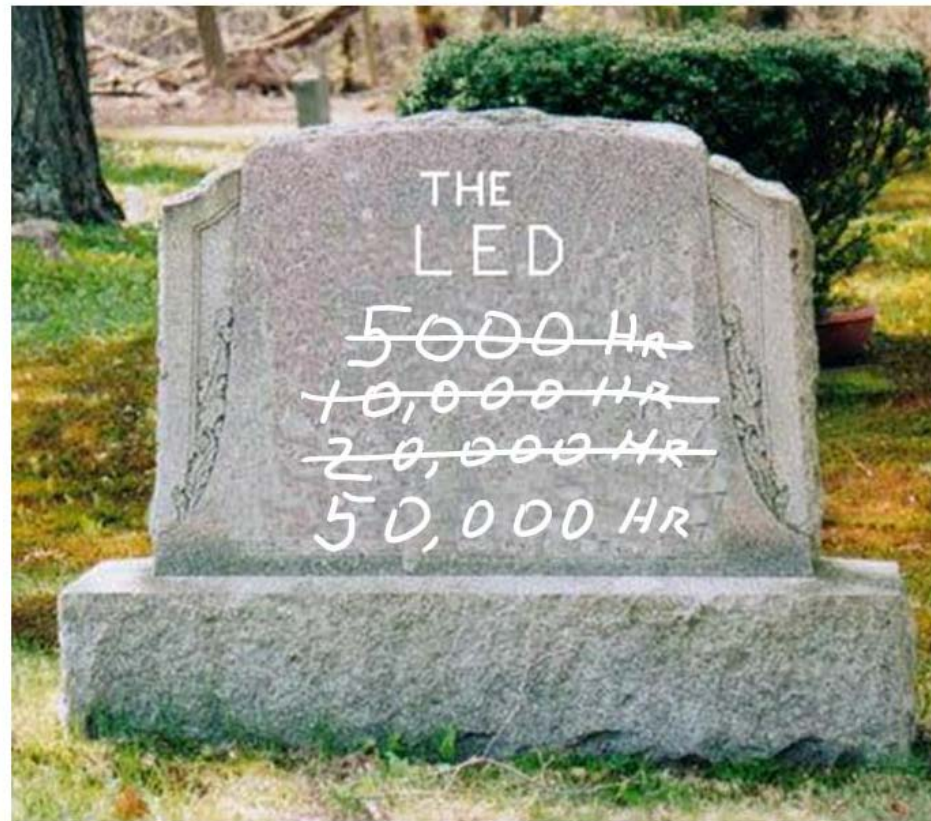


# How long do light sources last?



LED Lifetime

## How long do they last?





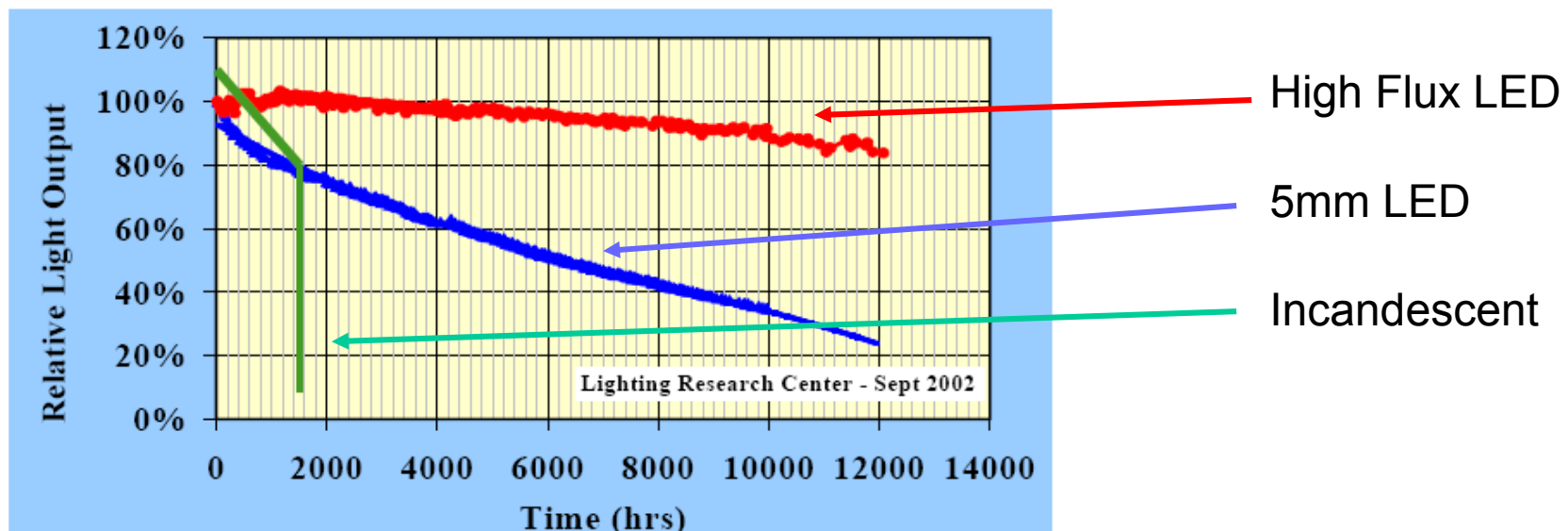
# How long do light sources last?

## What do we mean by Lifetime?

Traditionally Lifetime was the time it took for 50% of the population of incandescent bulbs to fail

Many light sources don't fail catastrophically—Define EOL by reduction in light output from initial values for example 70% or 50% of initial value

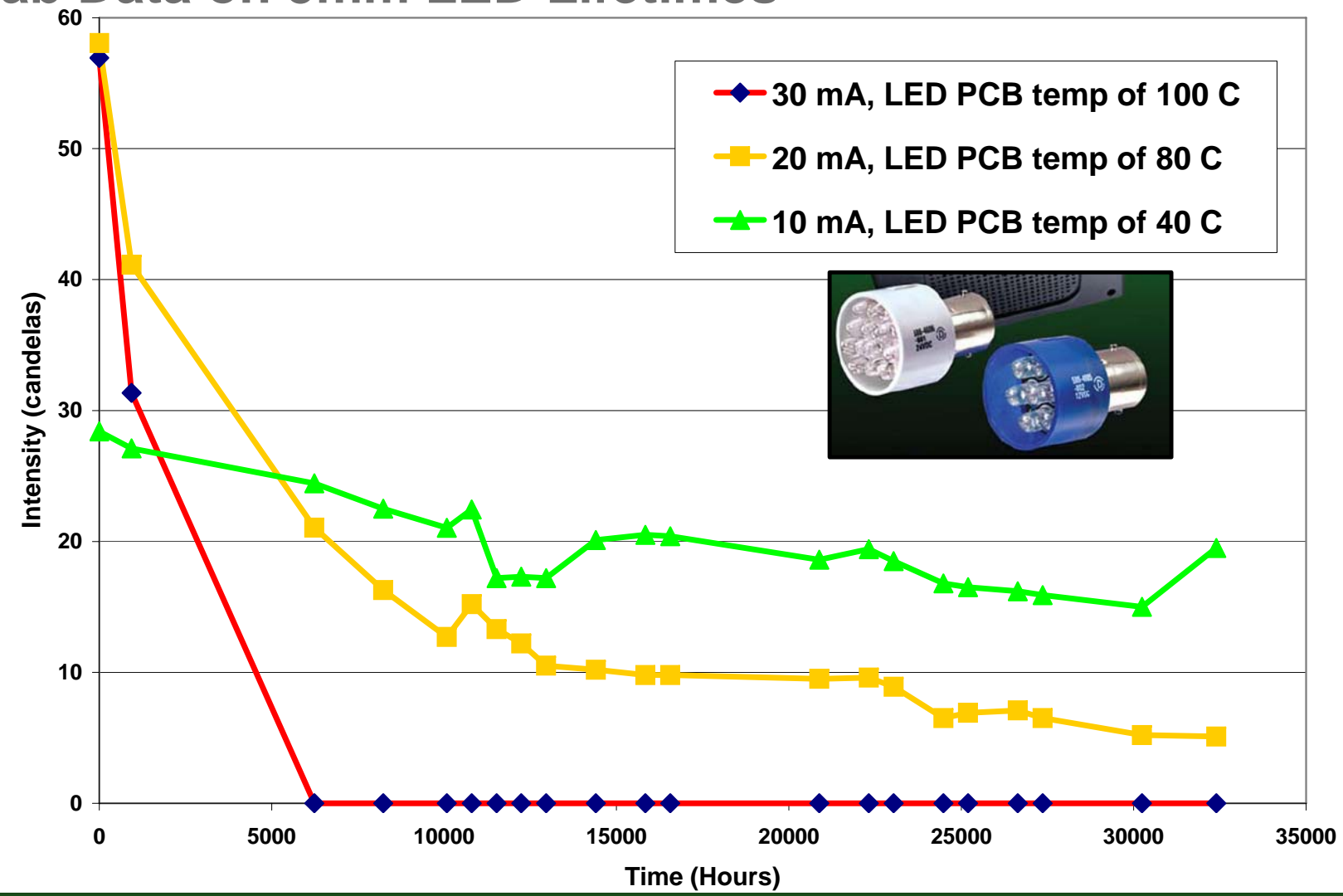
Under what conditions do we measure lifetime?





# How long to light sources last?

## Lab Data on 5mm LED Lifetimes



# Lifetime (half-life) shortens with increasing Temperature and Drive Current



## LW Y3SG

Exemplarische mittlere Lebensdauer<sup>2)</sup> Seite 17  
für typische Helligkeitsgruppe  
Exemplary median Lifetime<sup>2)</sup> page 17  
for typical Brightness Group

Bedingungen Conditions	mittlere Lebensdauer median Lifetime	Einheit Unit
$I_F = 15 \text{ mA}$ $T_A = 25^\circ\text{C}$	>50.000	Betriebsstunden operating hours
$I_F = 30 \text{ mA}$ $T_A = 85^\circ\text{C}$	4.500	Betriebsstunden operating hours

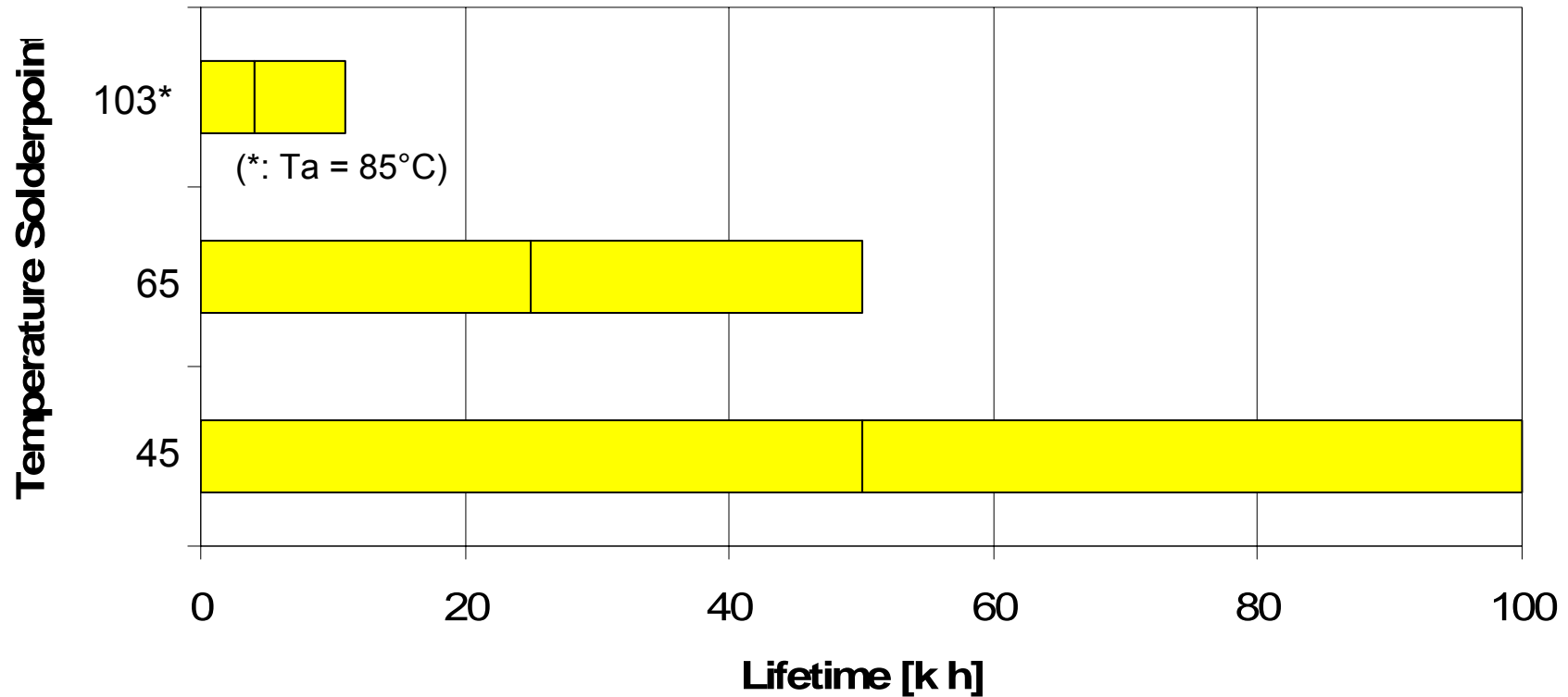
Data extracted from page 11 of LW Z3SG data sheet.

[Examples OSRAM](#)

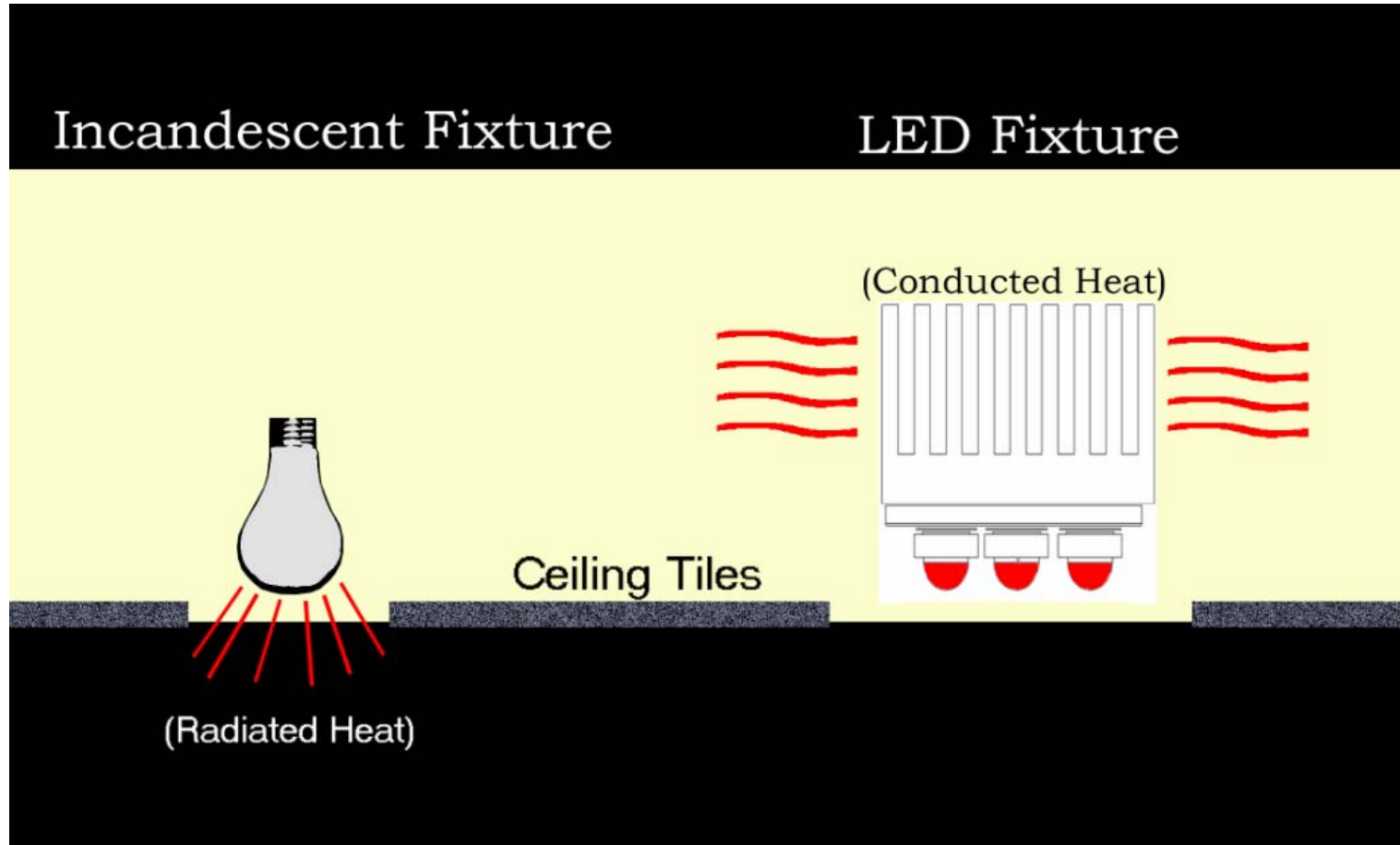
# Generic white LED lifetime vs. Temperature



**Power TOPLED® (LW\_E6SG) @ fixed  $I_f = 30$  mA**



# Thermal Management Issues



# Thermal Management Issues

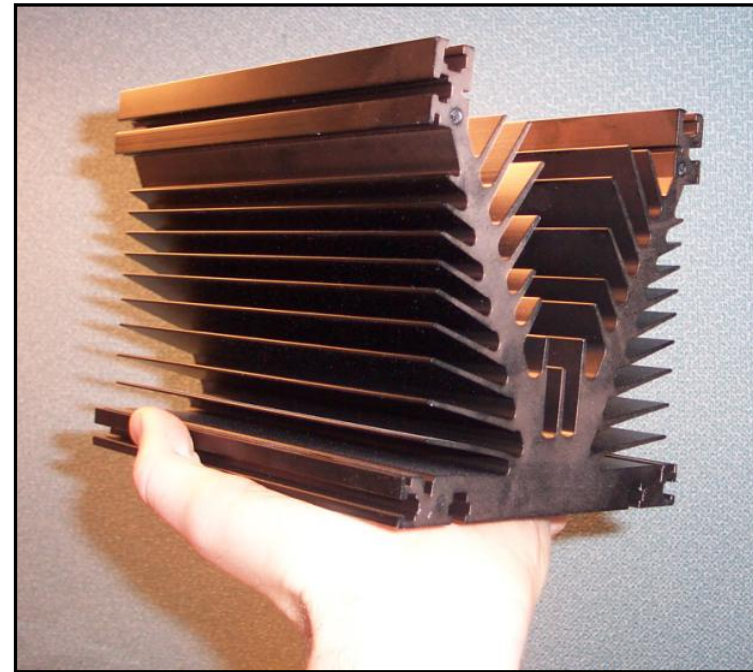


Which heat sink do I need?



40 °C/W

or

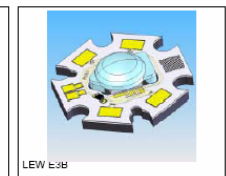
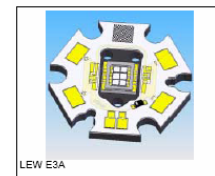
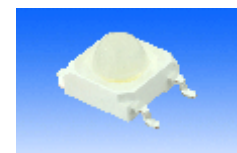
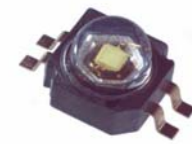
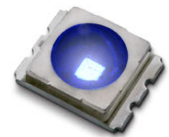


0.4 ° C/W

# Manufacturers Examined

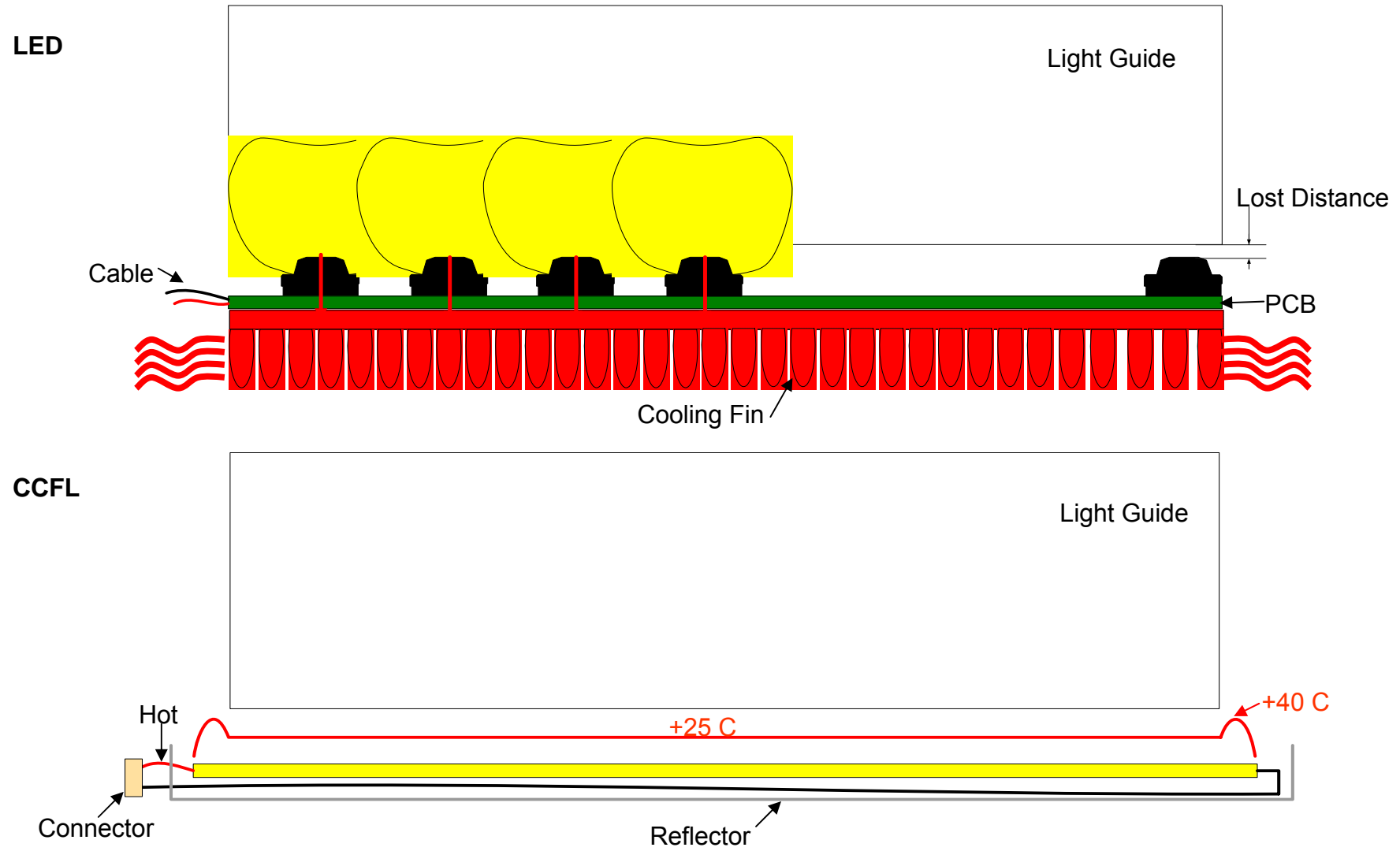


- Cree
  - XLamp Series
- LumiLeds
  - Luxeon Series
  - K2 Series
- Nichia
  - Jupiter Series
- Osram
  - Golden Dragon Series
- Seoul Semiconductor
  - Z-Power Series



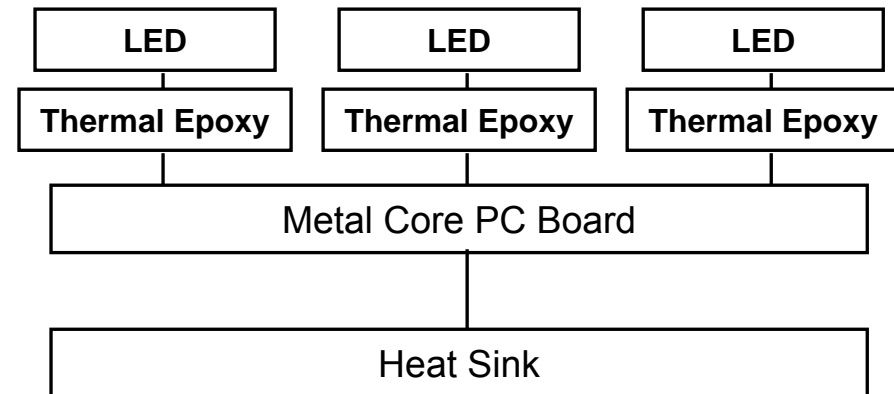
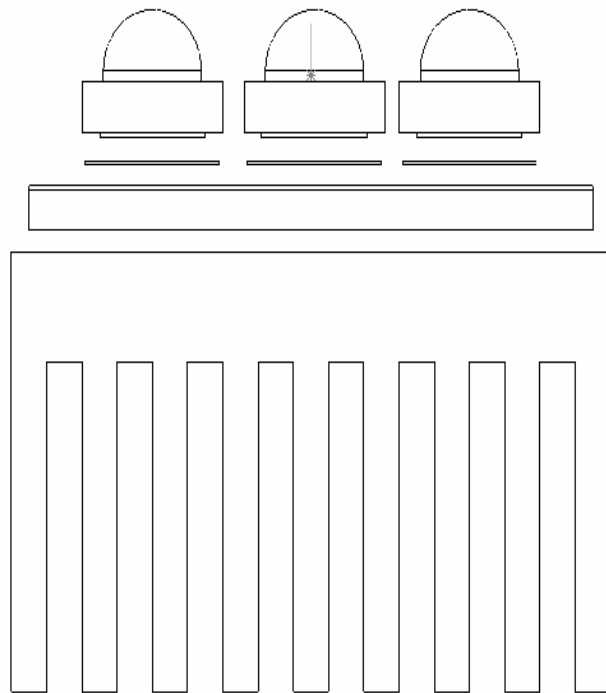


# Temperature



# Thermal Management Issues

## Calculating Safe Junction Temperatures

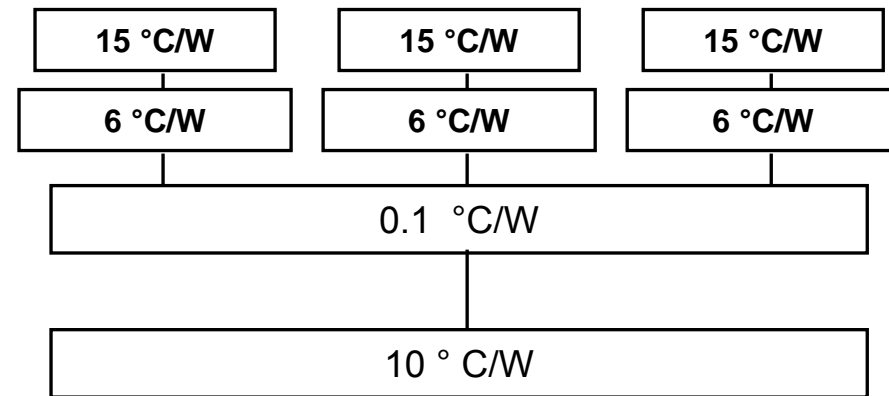
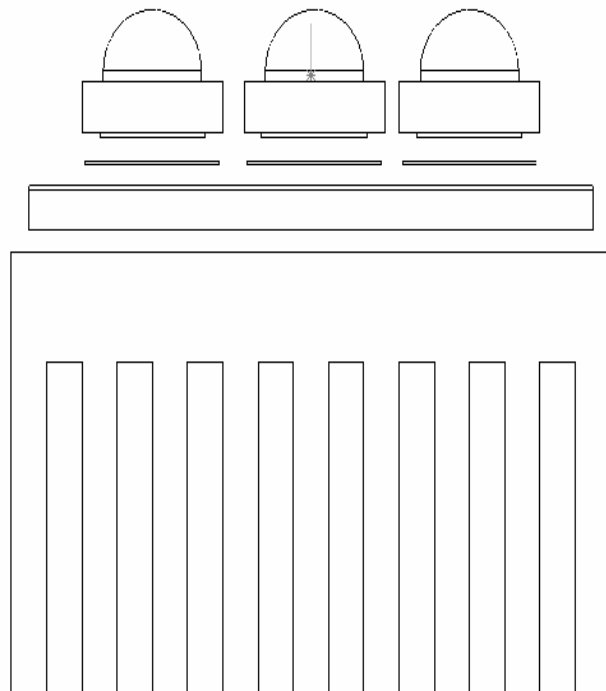


$$T_{\text{Junction}} = T_A + (P_{\text{LED}}) \cdot (R\Theta_{\text{LED}}) + (P_{\text{LEDs}}) \cdot (R\Theta_{\text{Heat sink}})$$

# Thermal Management Issues

Increasing from 1W to 3W LEDs

Operating temperature of +25°C



$$T_{Junction} = 25^{\circ}\text{C} + (1\text{W}) \cdot (21^{\circ}\text{C}/\text{W}) + (3\text{W}) \cdot (10.1^{\circ}\text{C}/\text{W})$$

$$T_{Junction} = 76.3^{\circ}\text{C}$$

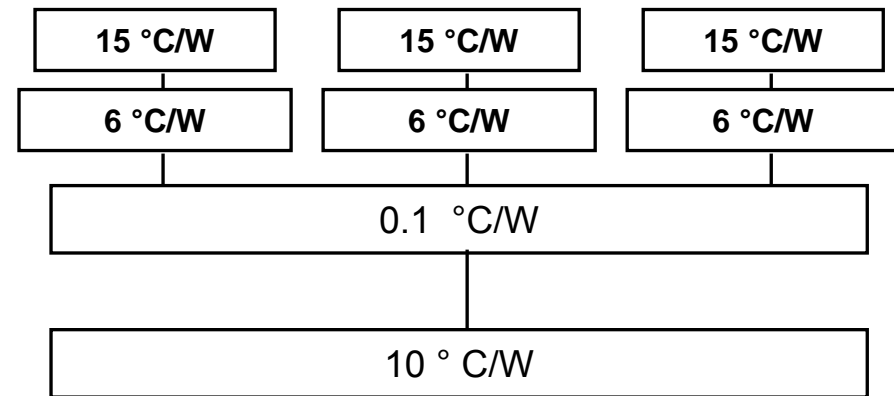
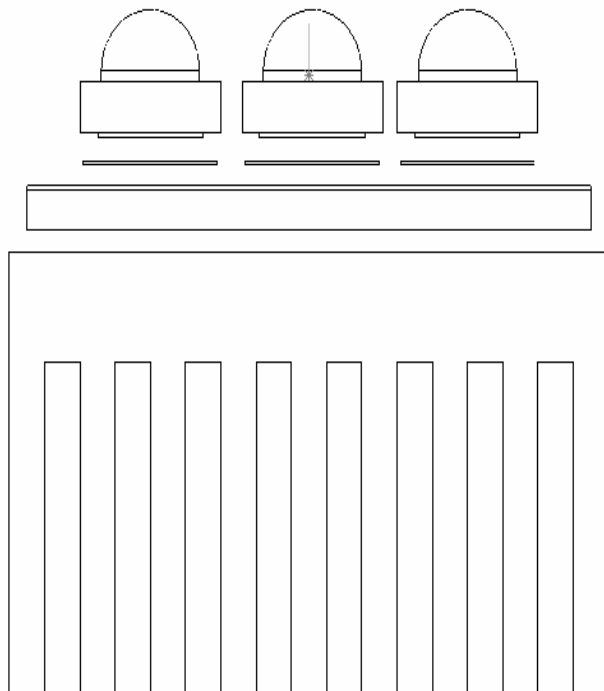
$$T_{Junction} = 25^{\circ}\text{C} + (3\text{W}) \cdot (19^{\circ}\text{C}/\text{W}) + (9\text{W}) \cdot (10.1^{\circ}\text{C}/\text{W})$$

$$T_{Junction} = 172.9^{\circ}\text{C}!!!$$

# Thermal Management Issues

Increasing from 1W to 3W LEDs

Operating temperature of +60°C



$$T_{Junction} = 60^{\circ}C + (1W) \cdot (21^{\circ}C/W) + (3W) \cdot (10.1^{\circ}C/W)$$

$$T_{Junction} = 111,3^{\circ}C$$

$$T_{Junction} = 60^{\circ}C + (3W) \cdot (19^{\circ}C/W) + (9W) \cdot (10.1^{\circ}C/W)$$

$$T_{Junction} = 207,9^{\circ}C!!!$$

# Datasheet Lumens vs Actual Lumens



1-Watt LEDs, 25 °C ambient temperature

Datasheet: 45 Lumens at a 25 °C die temperature

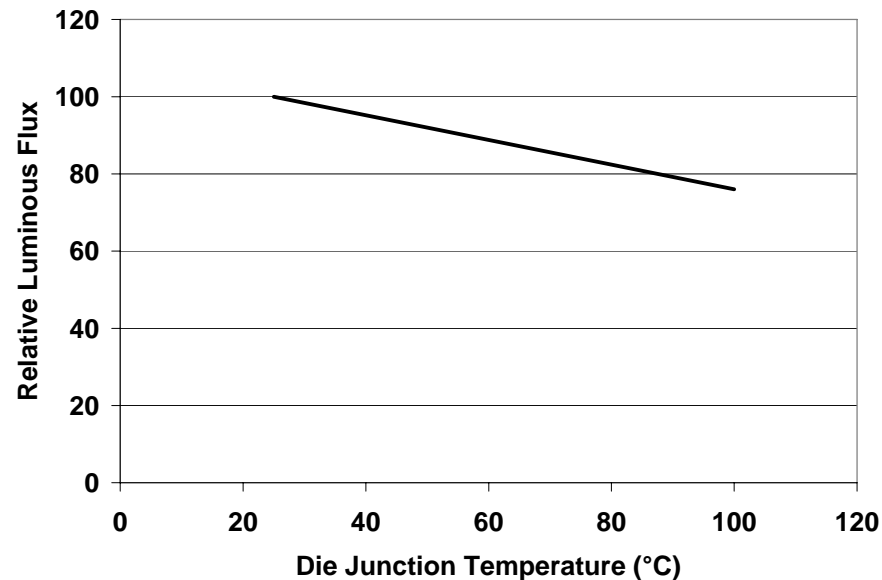
Dynamic resistance: 1  $\Omega$

Temperature coefficient of  $V_f$ : -2.0 mV/ °C

15 °C/W thermal resistance for the LED

6 °C/W thermal resistance for the thermal epoxy and PCB dielectric

10 °C/W for the heatsink, board interface, etc.



# Cool White LED Comparison



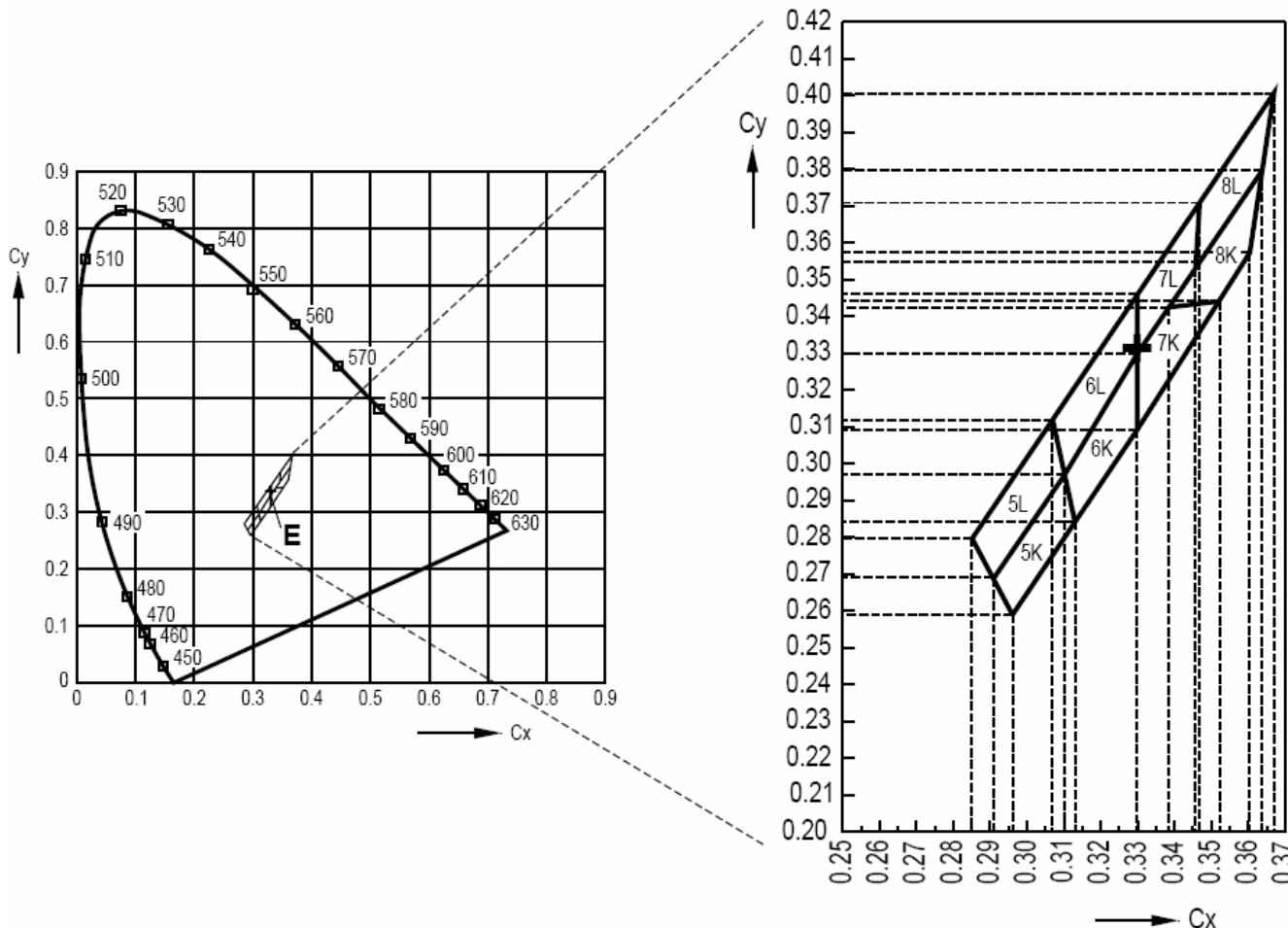
	Dice #	Viewing Angle Degees	350 mA	500 mA	700 mA	1000 mA	1400 mA	1500 mA	Typical Current mA	Typical Voltage Vf	Typical Power W	Thermal Resistance °C/W	Rise LED Only °C	Max Junction °C	CRI
Osram LW W5SG Cool	1	120	21-39	41					350	3.8	1.3	9	12	125	80
Osram ZW W5SG Cool	1	120	33-71	60					350	3.2	1.1	15	17	125	80
Osram LW W5SN Cool	1	120			52-97				700	3.8	2.7	8	21	135	80
Osram LW W5SM Cool	1	120		64					350	3.2	1.1	15	17	125	80
Osram LEW E3A Cool	6	120			300				700	22.5	15.8	3.6	57	150	80
Osram LEW E3B Cool	6	120			420				700	22.5	15.8	3.6	57	125	80
Osram LEW E2A Cool	4	120			200				700	15	10.5	5	53	150	80
Osram LEW E2B Cool	4	120			280				700	15	10.5	5	53	125	80
Lumileds LXHL-PW01 Cool	1	120	45						350	3.42	1.2	15	18	135	70
Lumileds LXHL-DW01 Cool	1	Side-emit	40.5						350	3.42	1.2	15	18	135	70
Lumileds LXHL-BW02 Cool	1	Batwing	45						350	3.42	1.2	15	18	135	70
Lumileds LXHL-PW09 Cool	1	120			65	80			700	3.7	2.6	13	34	135	70
Lumileds LXHL-DW09 Cool	1	Side-emit			58	70			700	3.7	2.6	13	34	135	70
Lumileds LXHL-PW03 Cool	4	150			87.4				700	6.84	4.8	8	38	135	70
Lumileds LXX2-PW etc Cool	1	150	52.5		87.5	110	135		1000	3.72	3.7	9	33	150	70
Nichia NCCW002, etc Cool	1	35,70,120	42	?					350	3.7	1.3	17	22	105	80
Nichia NS6W083 Cool	4	120	60	?					350	3.6	1.3	10	13	120	80
Cree XL7090 Cool	1	100	52		?				350	3.5	1.2	17	21	125	75
Cree 3XL7090 Cool	1	100			76				700	4	2.8	17	48	145	75
Cree XL7090XR Cool	1	100	53.5		?				350	3.5	1.2	8	10	145	75
Seoul Semi W10190 Cool	1	70,110	52						350	3.5	1.2	8	10	125	70
Seoul Semi W10290 Cool	2	70,110			103				700	3.5	2.5	6	15	125	70
Seoul Semi W10490 Cool	4	70,110				178			1400	3.5	4.9	4	20	125	70
Cotco LD-700AWN1-70 Cool	1	70	27						350	3.6	1.3	15	19	125	

# White is White is White

## Binning Issues



### Osram White Binning

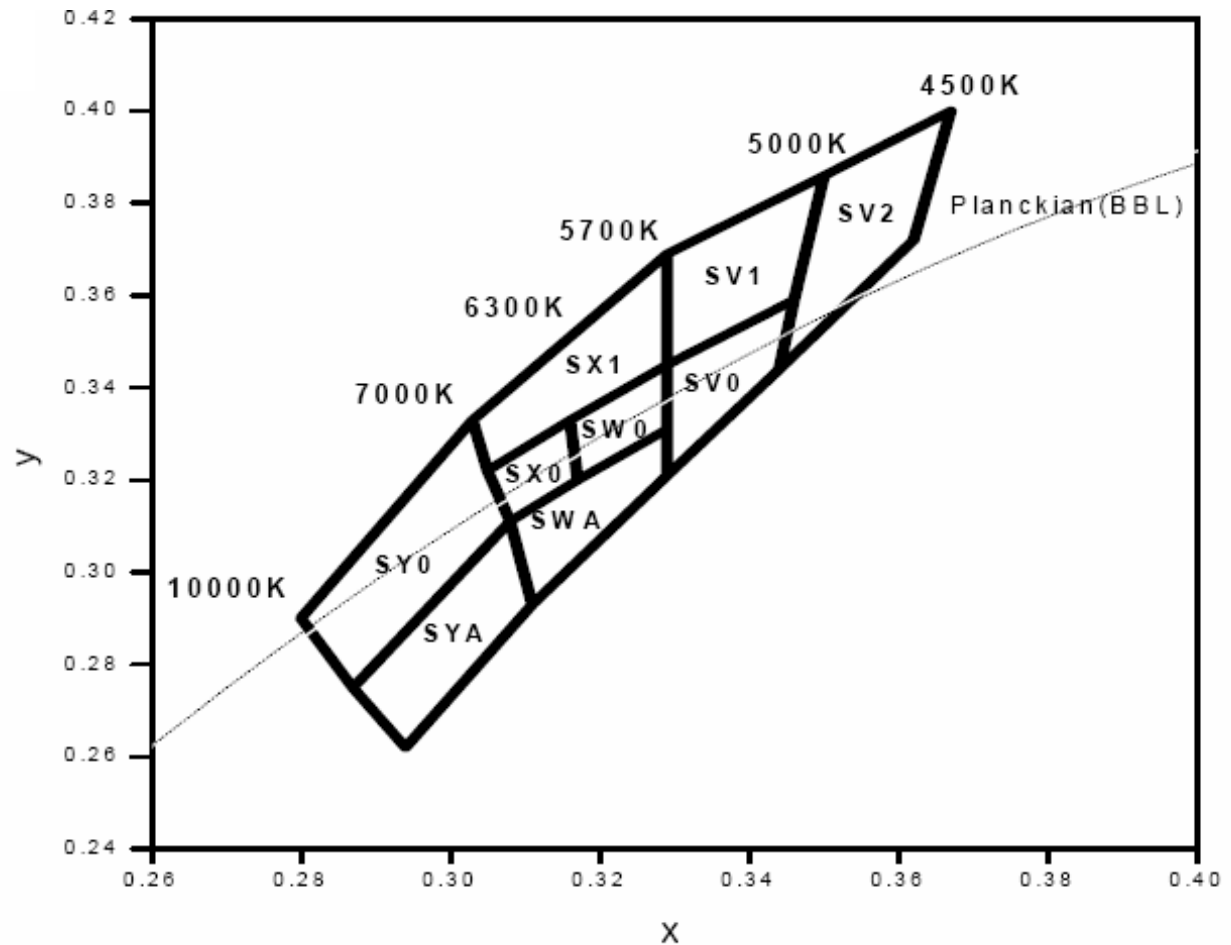


# White is White is White

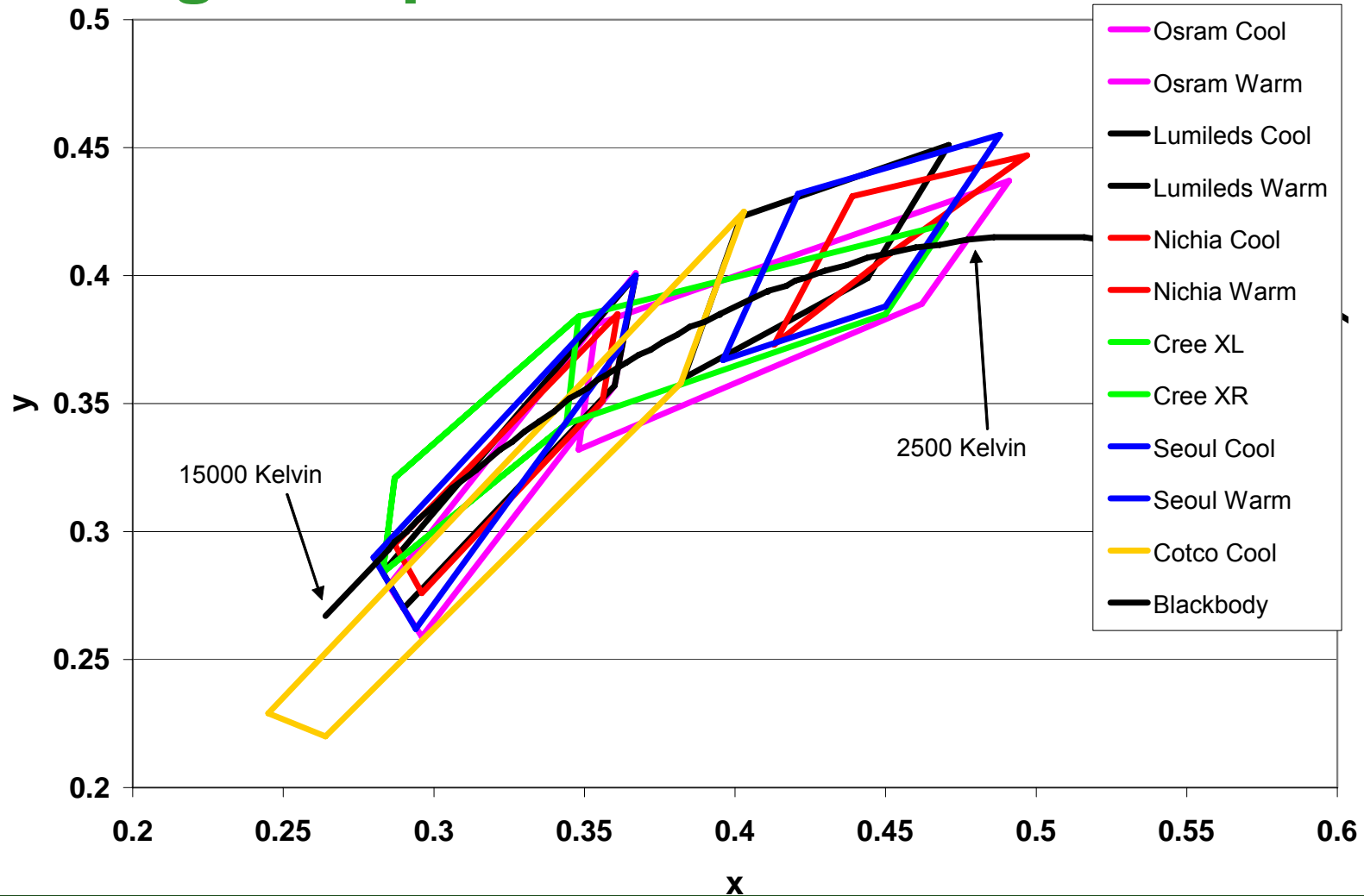
## Binning Issues



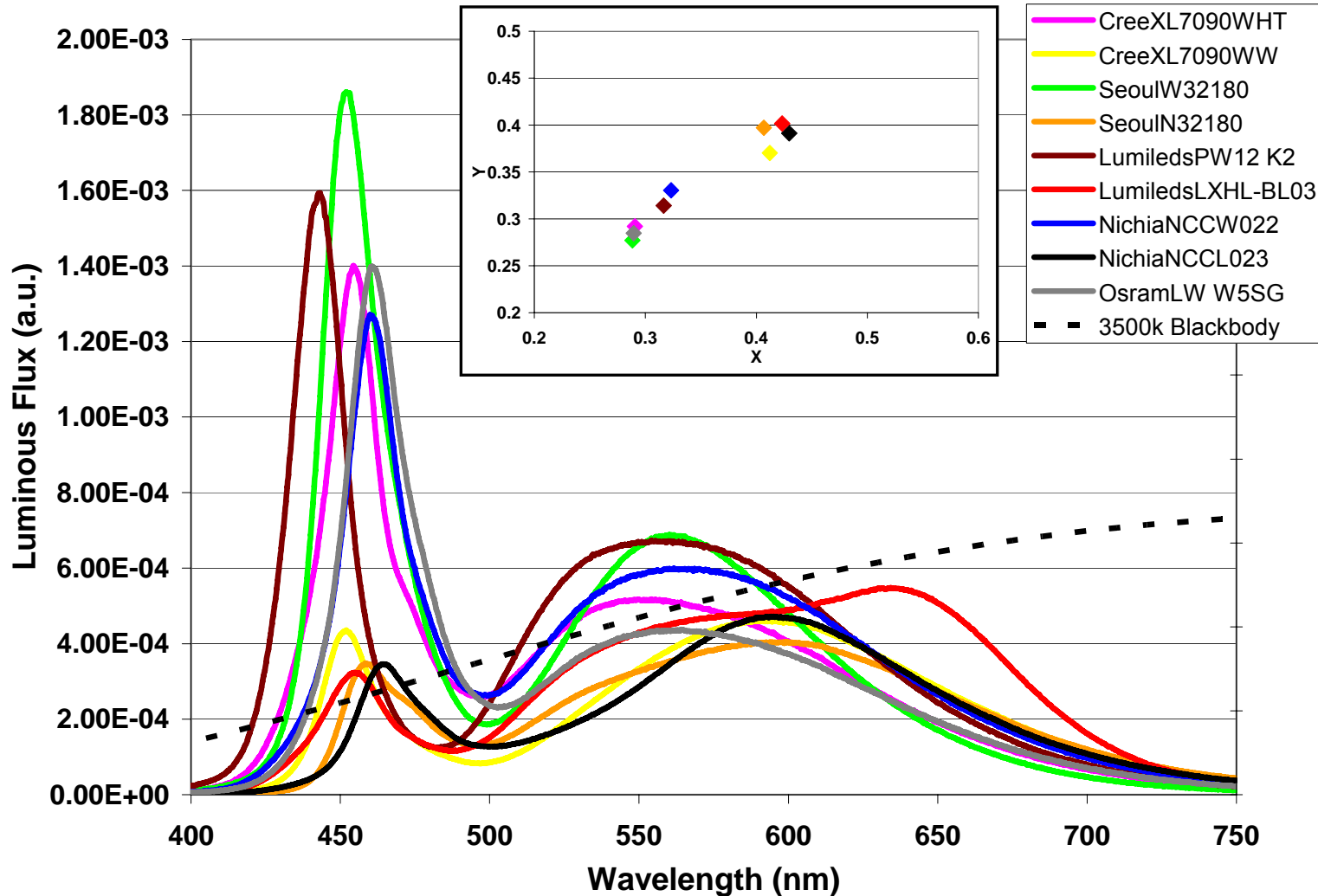
### Seoul White Binning



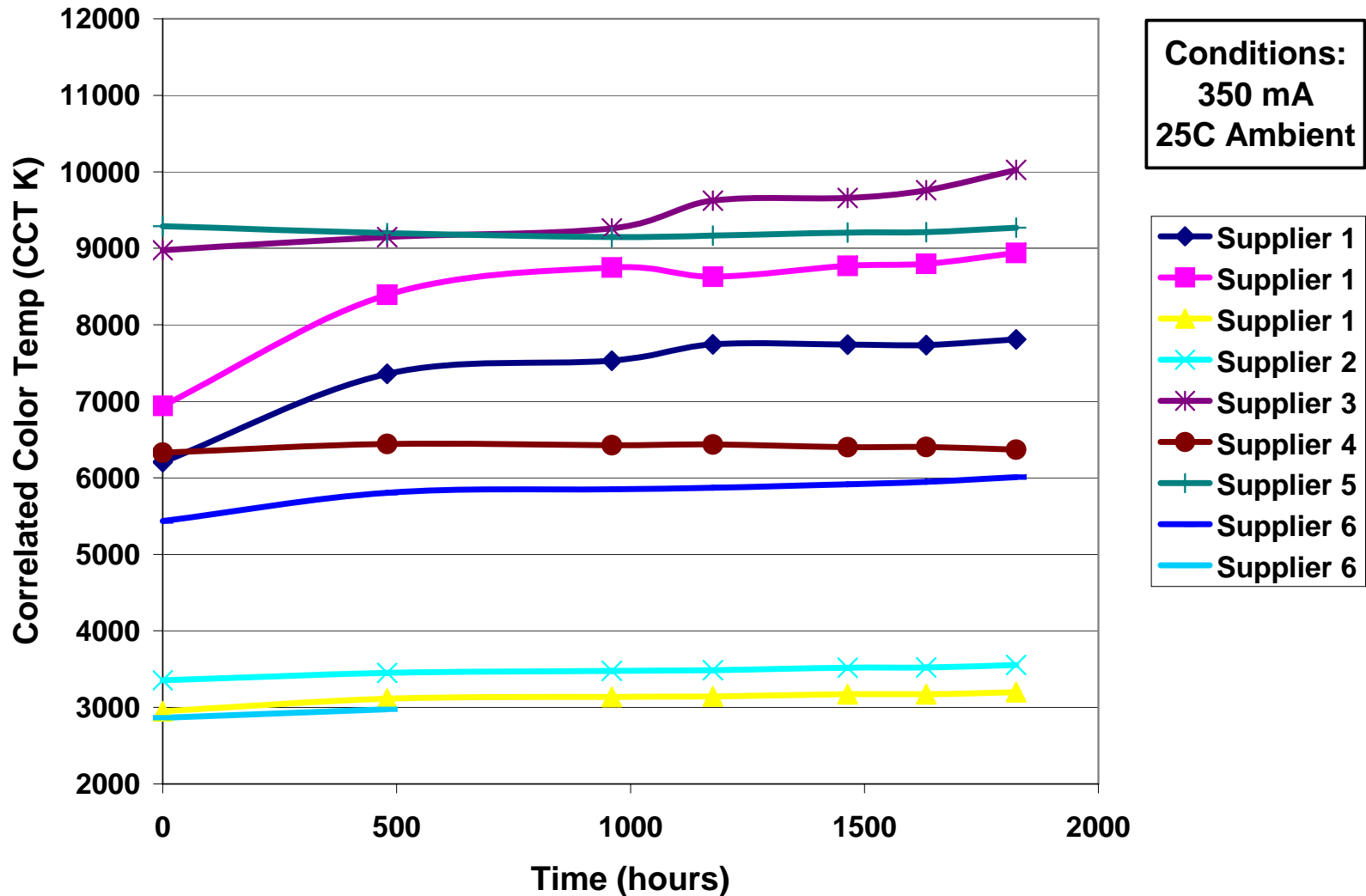
# Chromaticity Binning Comparison



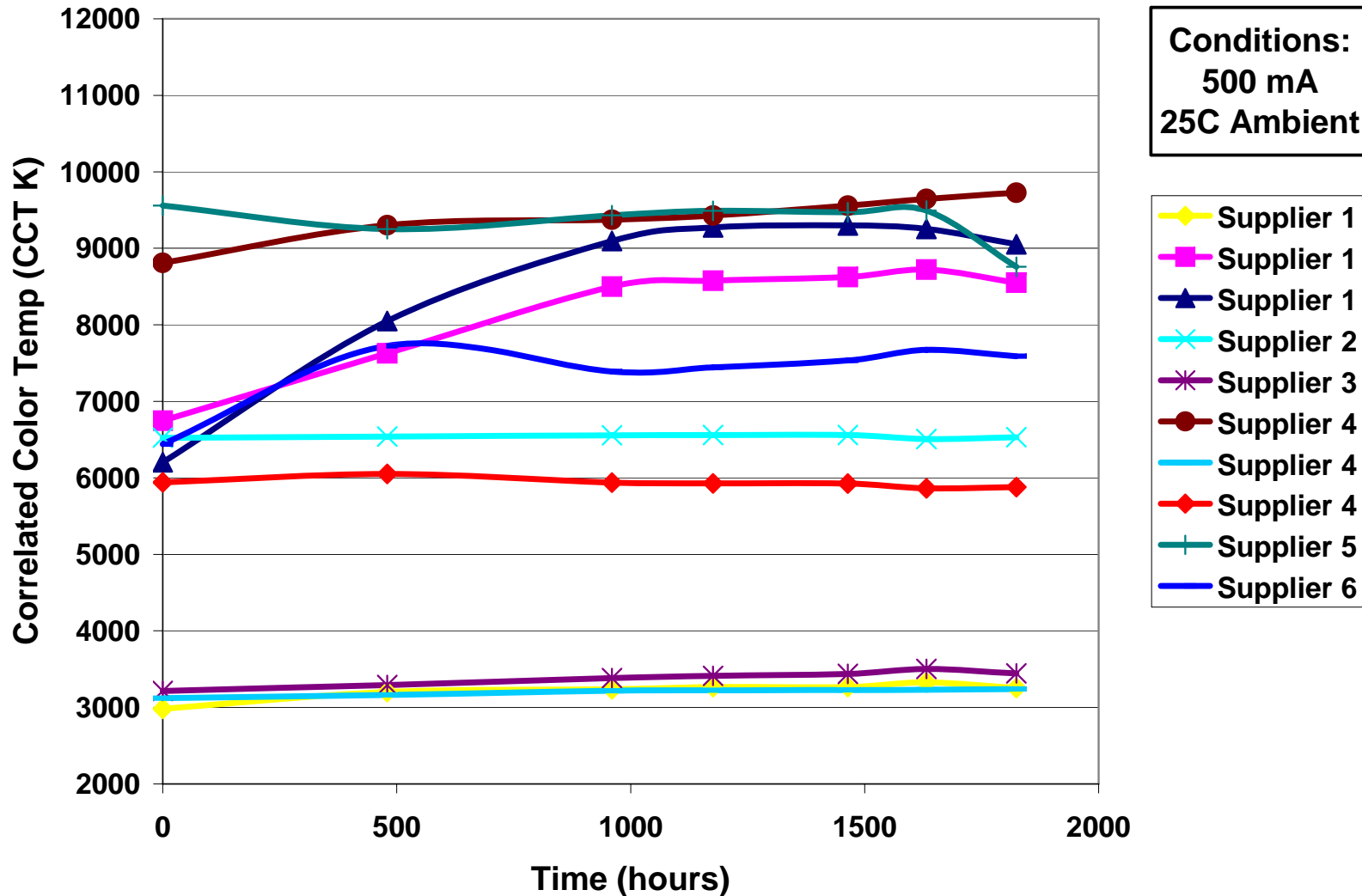
# Spectral and Chromaticity Measurements



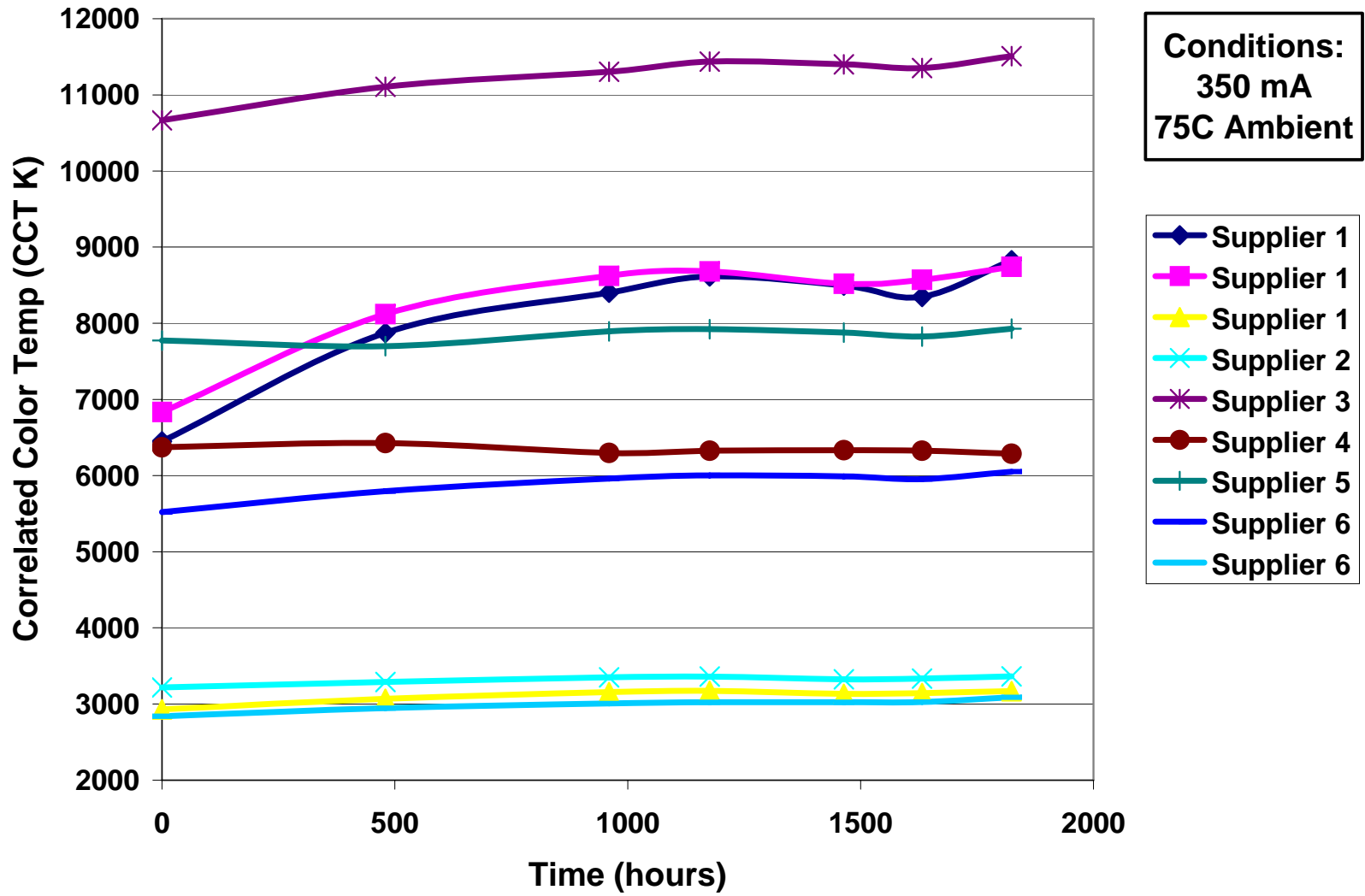
# CCT Change with Time



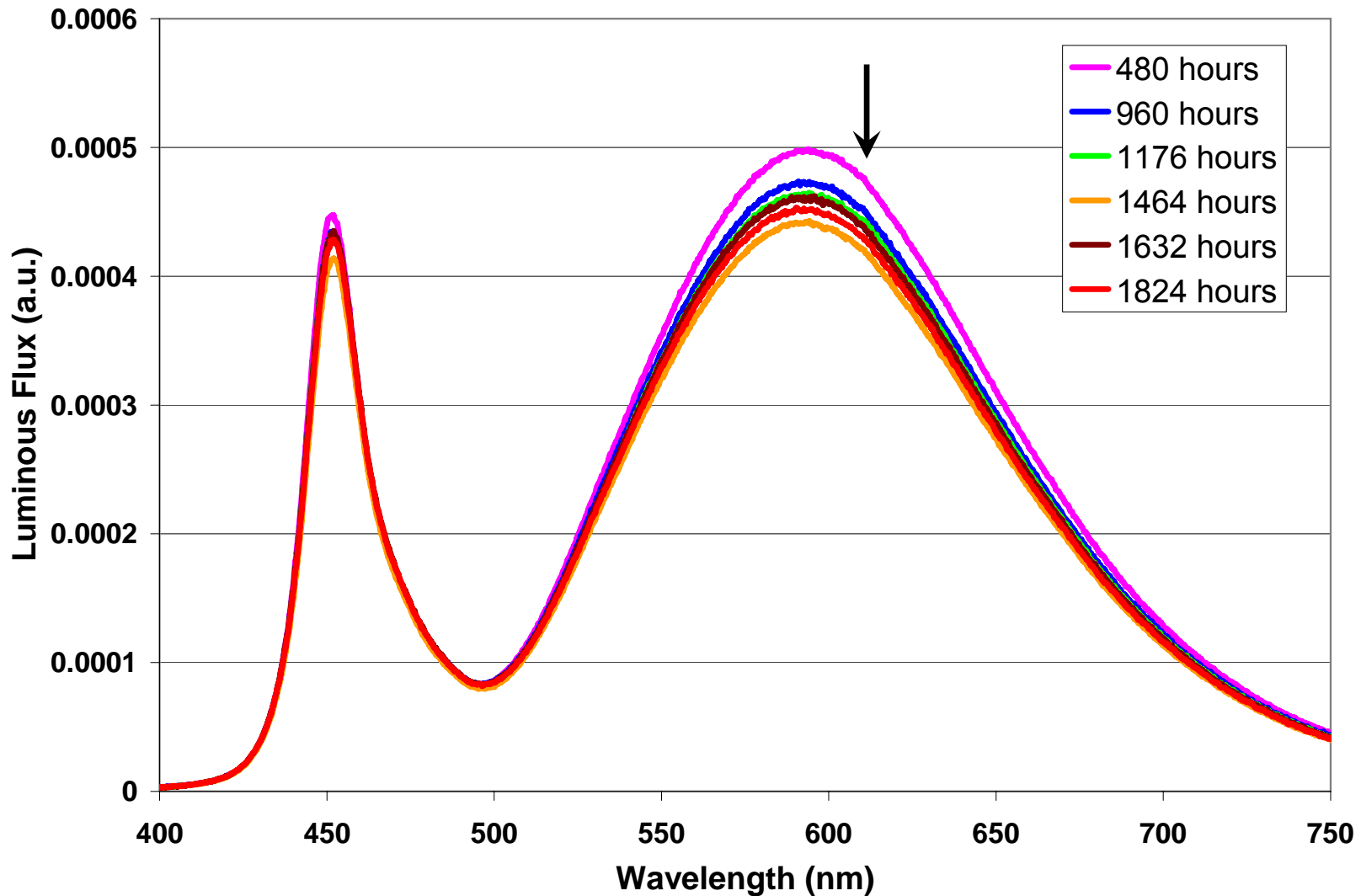
# CCT Change with Time



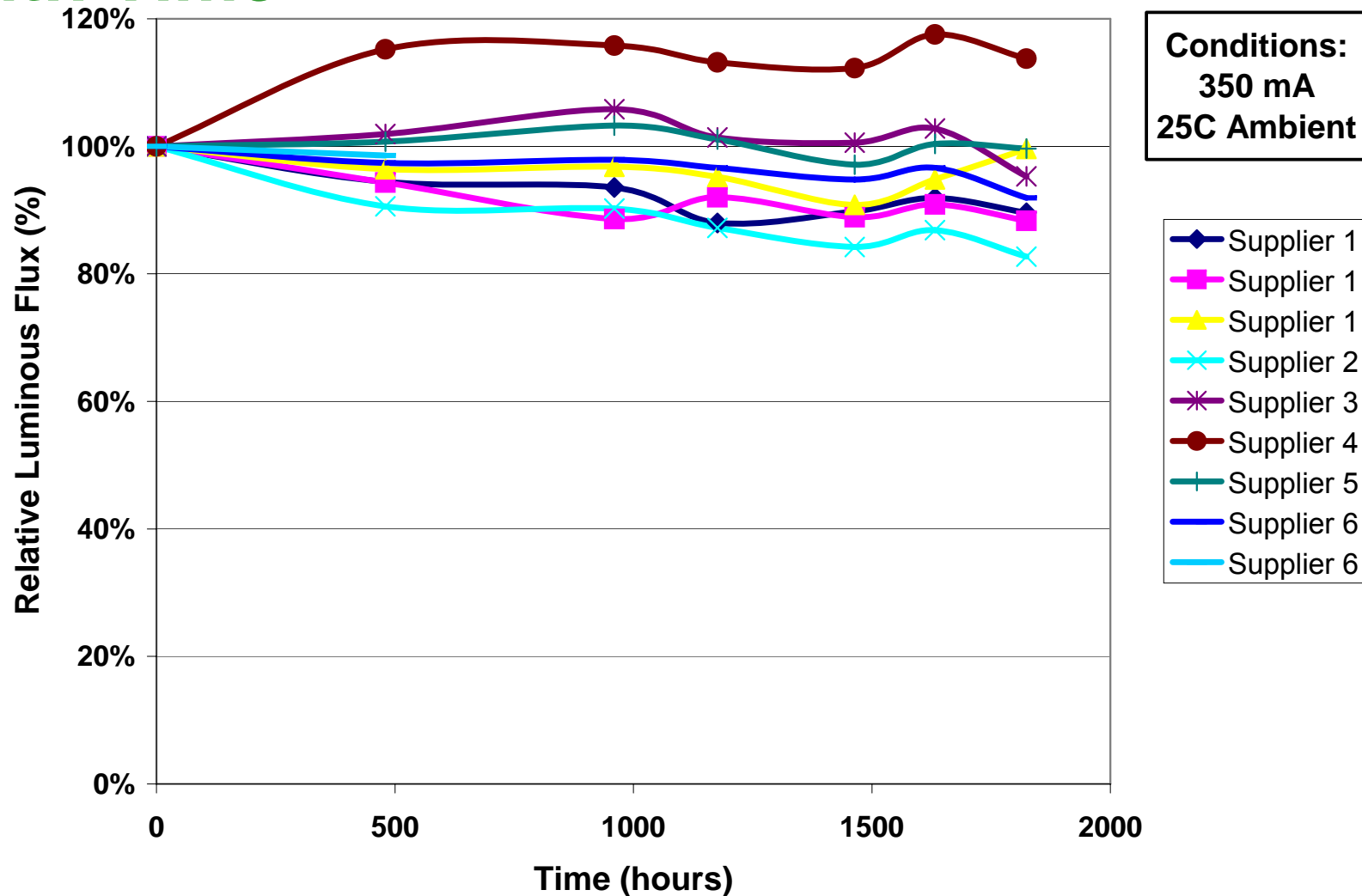
# CCT Change with Time



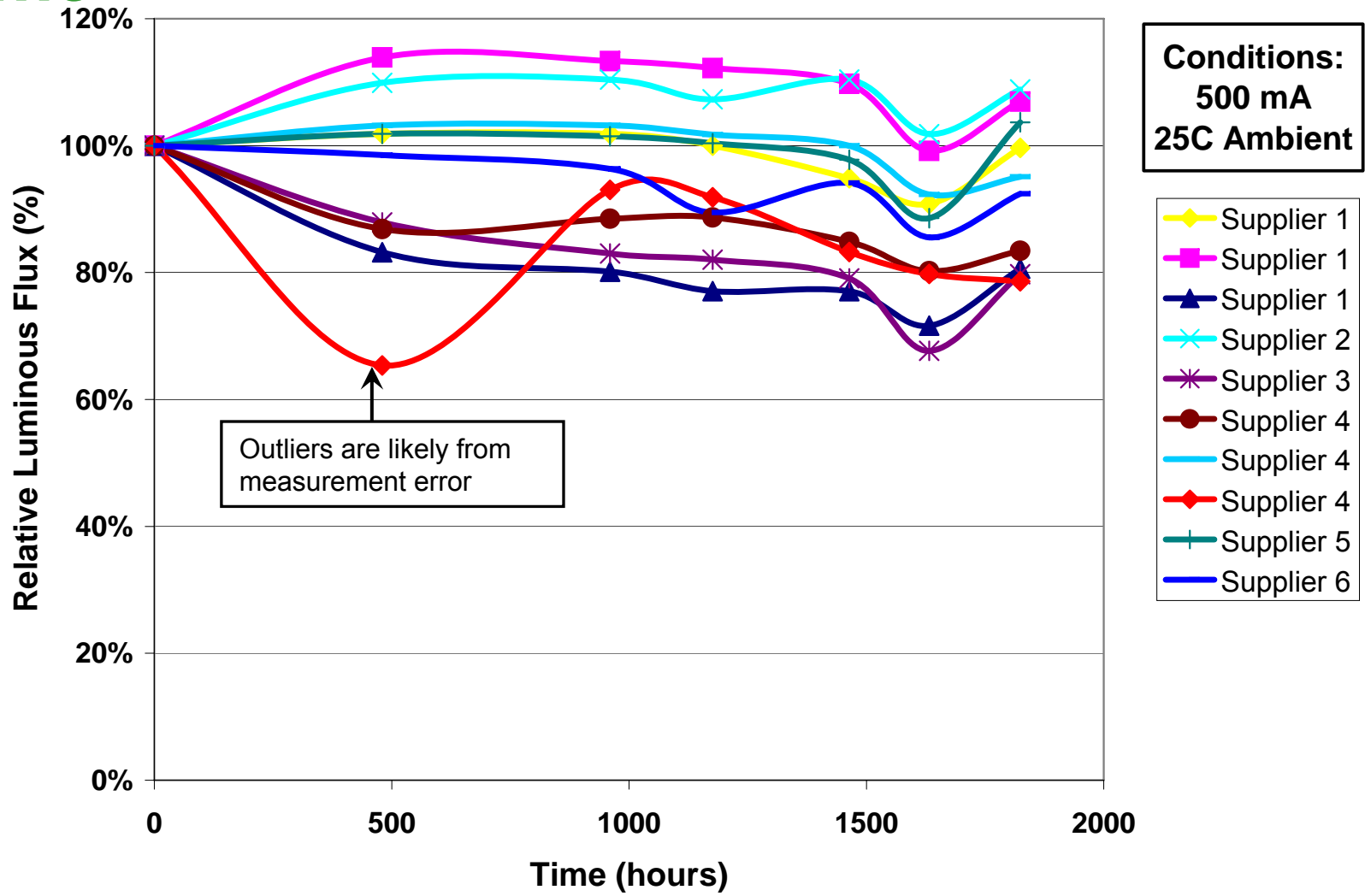
# CCT Change with Time



# Luminous Flux Change with Time

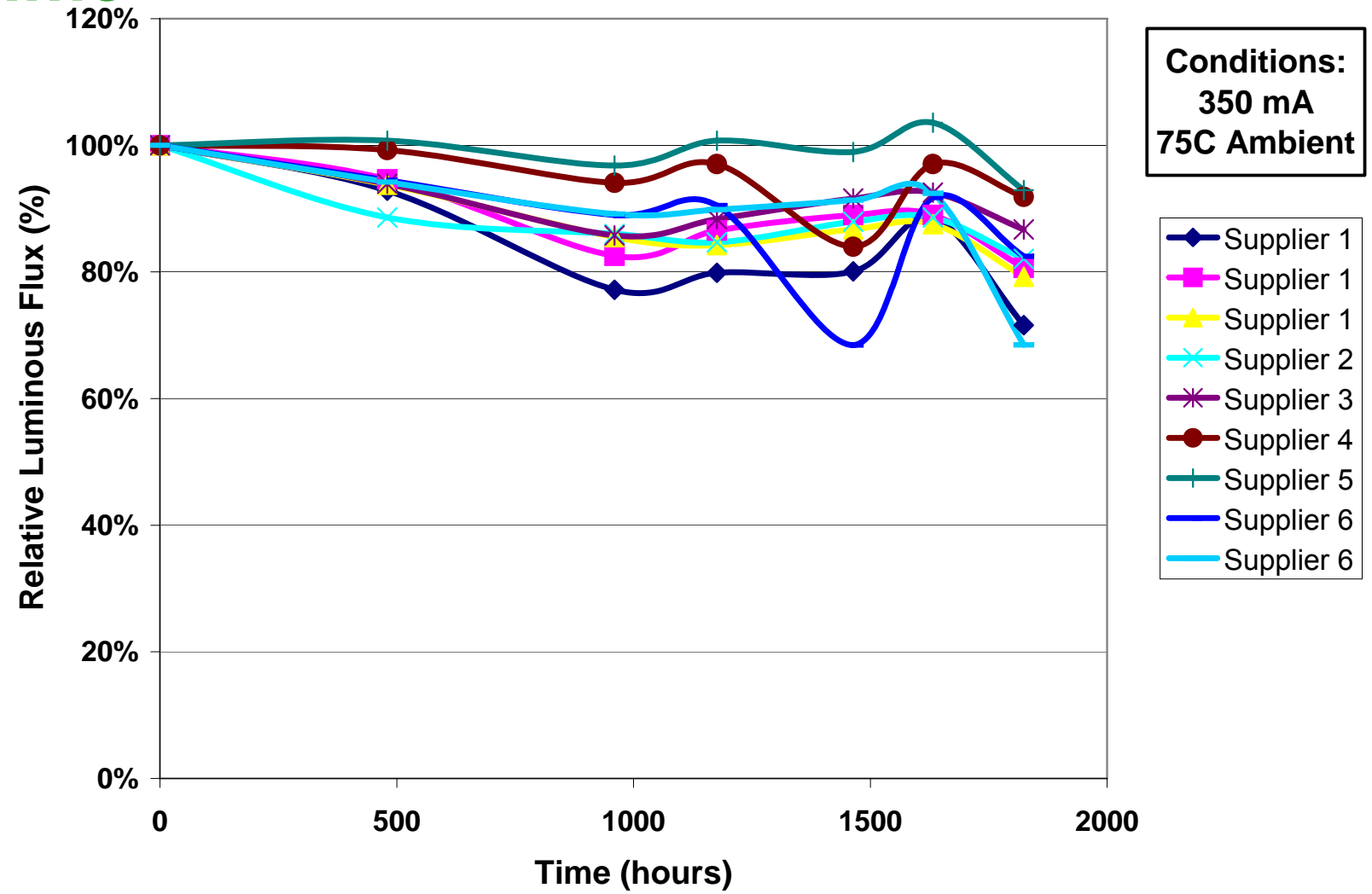


# Luminous Flux Change with Time





# Luminous Flux Change with Time



# The Cost of Light

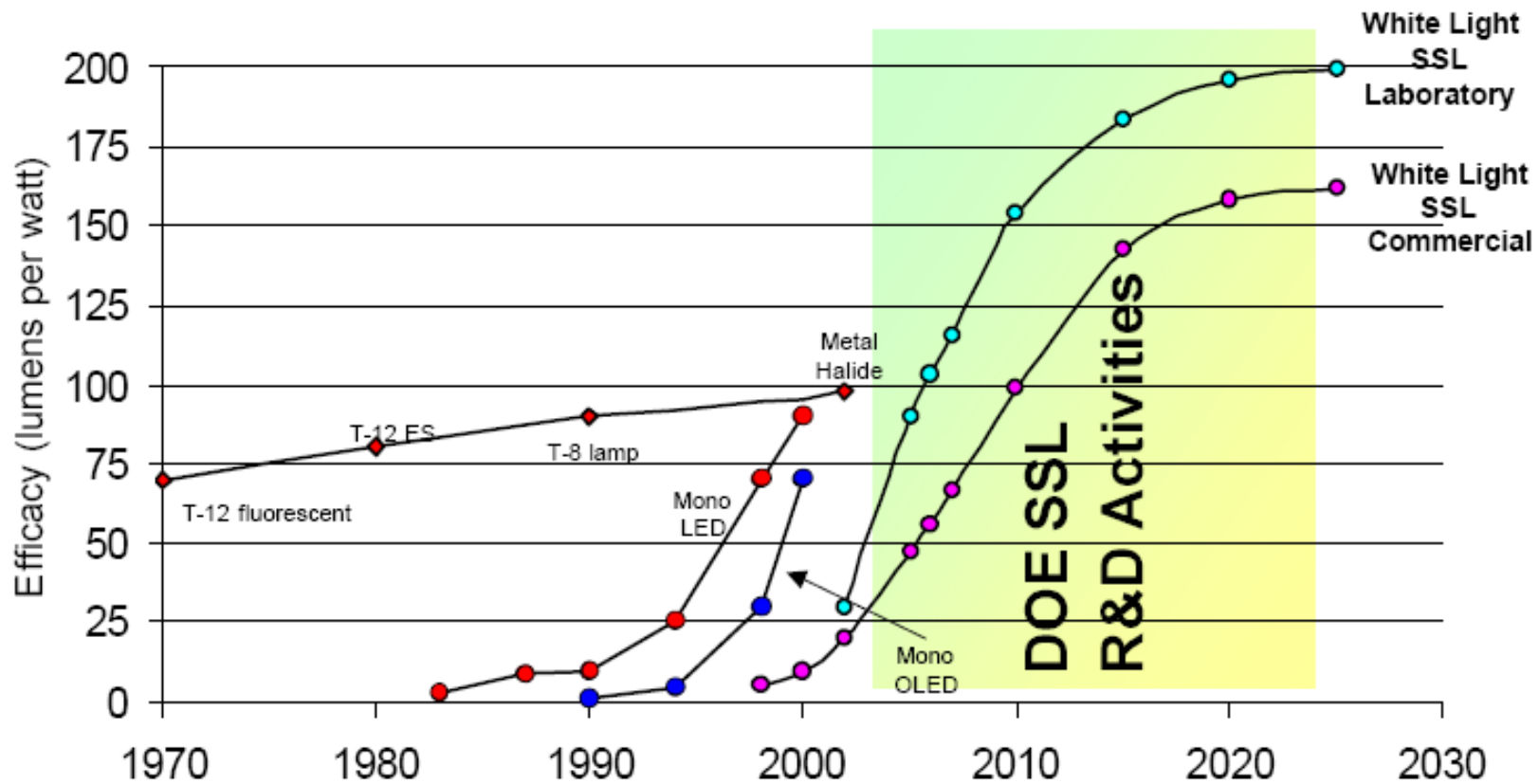


Lamp Type	Watts	Life	Initial Lumens	Maintained Lumens	Price	Luminous Efficiency	klm/\$	\$/Mlmh
Incandescent	60	1.000	850	850	\$0,90	14	0,94	\$12,82
Flourescent	32	24.000	3.000	2.900	\$1,50	91	2,00	\$1,18
High Pressure Mercury	250	24.000	11.000	8.500	\$21,00	34	0,52	\$3,06
High Pressure Sodium	250	24.000	28.000	27.000	\$27,00	108	1,04	\$0,97
Metal Halide	400	20.000	36.000	24.000	\$70,00	60	0,51	\$1,82
White LED (Luxeon K2)	5	50.000	100	75	\$3,50	15	0,03	\$8,67

$$\text{Cost of Light} = \frac{[p + h] / L + [W \times R]}{F} \quad (\text{in } \$ / \text{Mlm-hr})$$

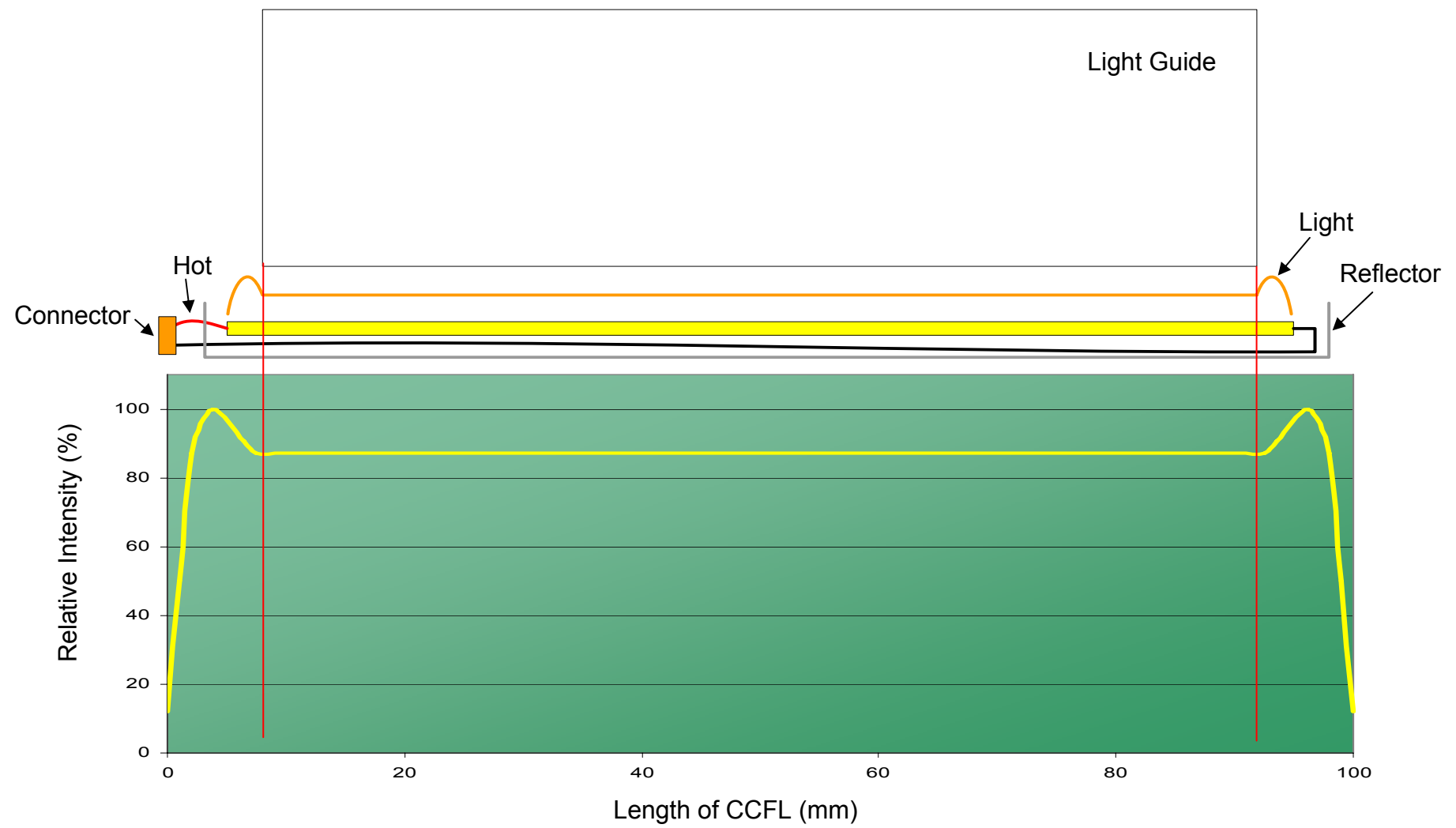
- Where
- p is the lamp price (in cents)
  - h is the labor cost to replace lamp (in cents) assumed to be 400¢
  - L is the lamp life (in hours)
  - F is the lamp flux output (in lumens)
  - W is the lamp input power (in watts)
  - R is the energy cost (in cents/kW-hr) assumed to be 10¢

# Luminous Efficiency Improvement Trends

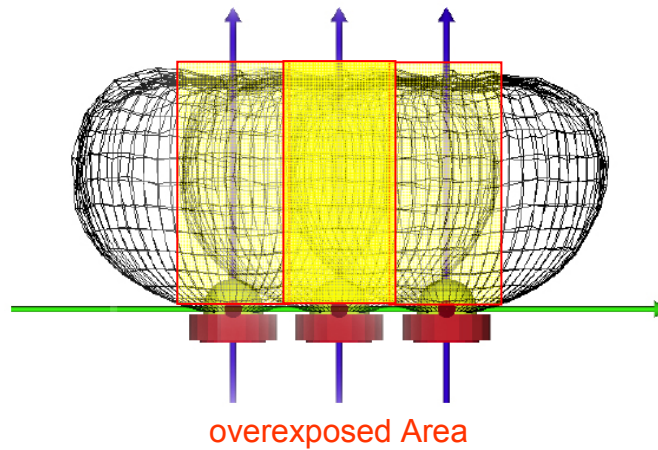
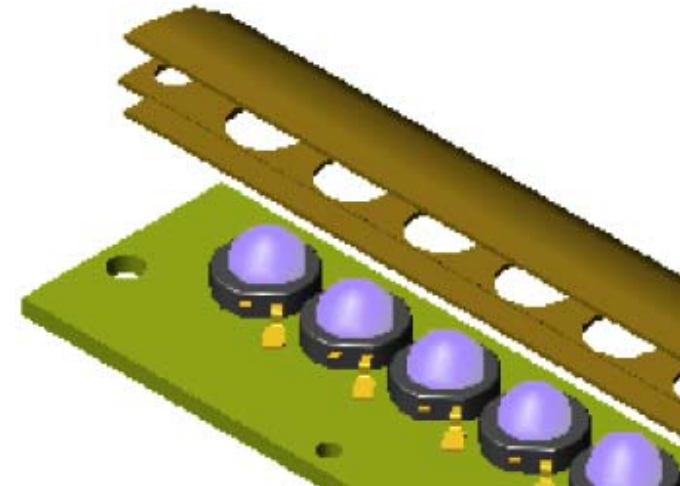
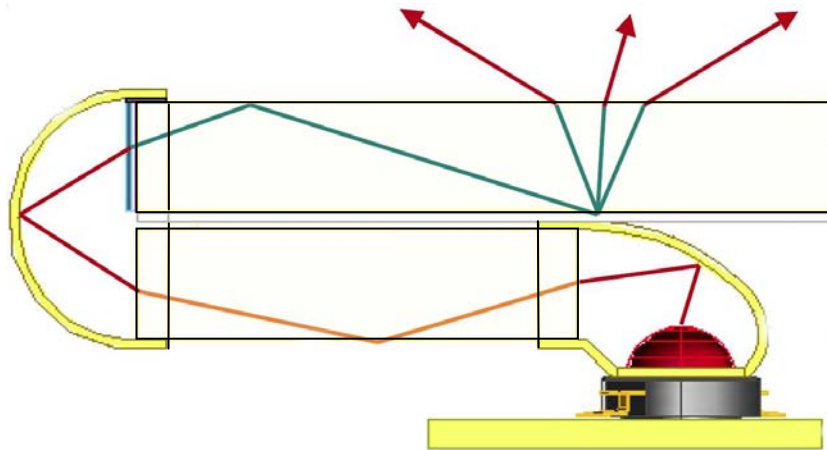




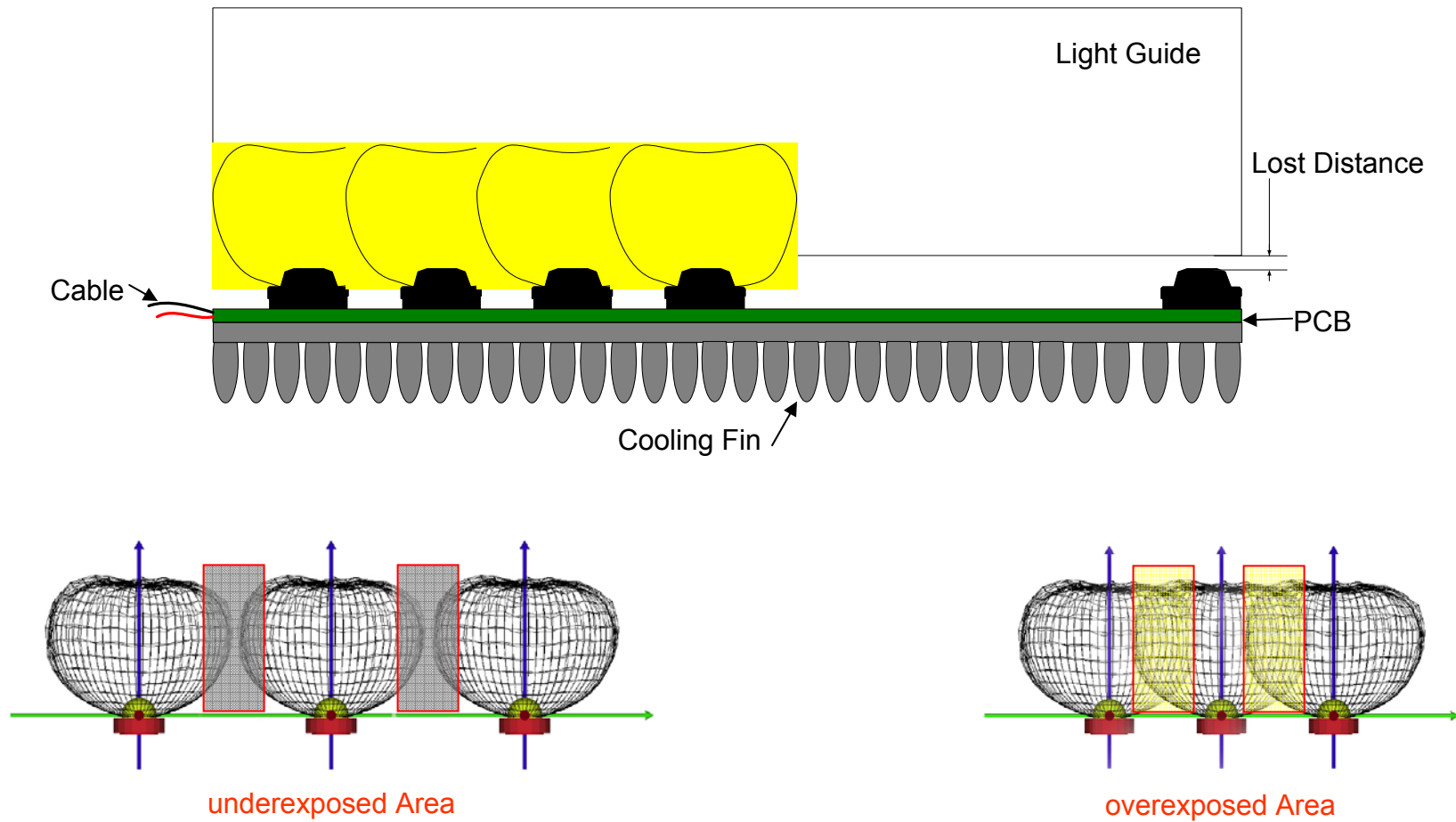
# CCFL – Light Intensity



# LED – On The Side

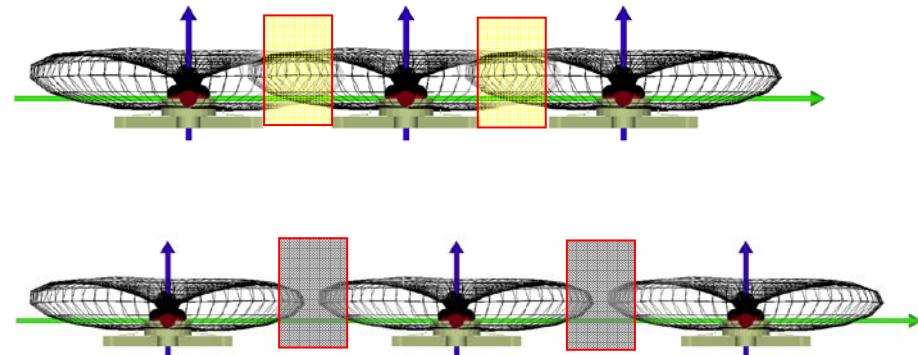
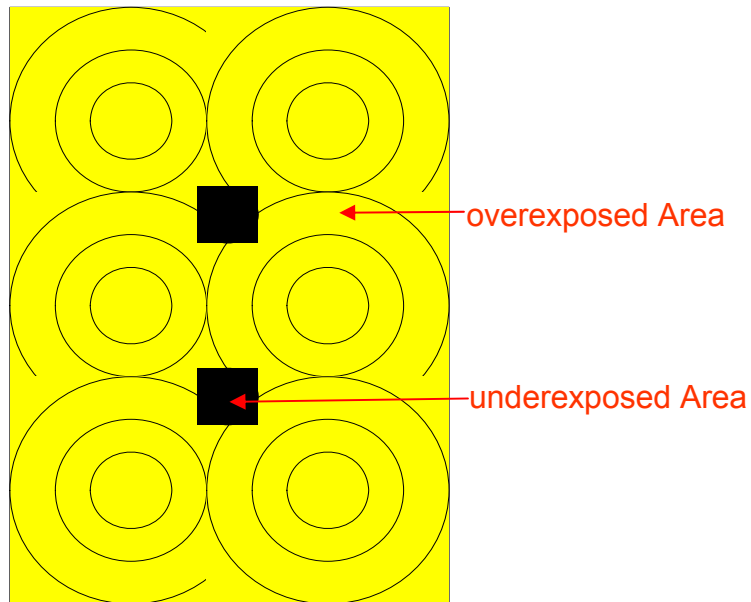
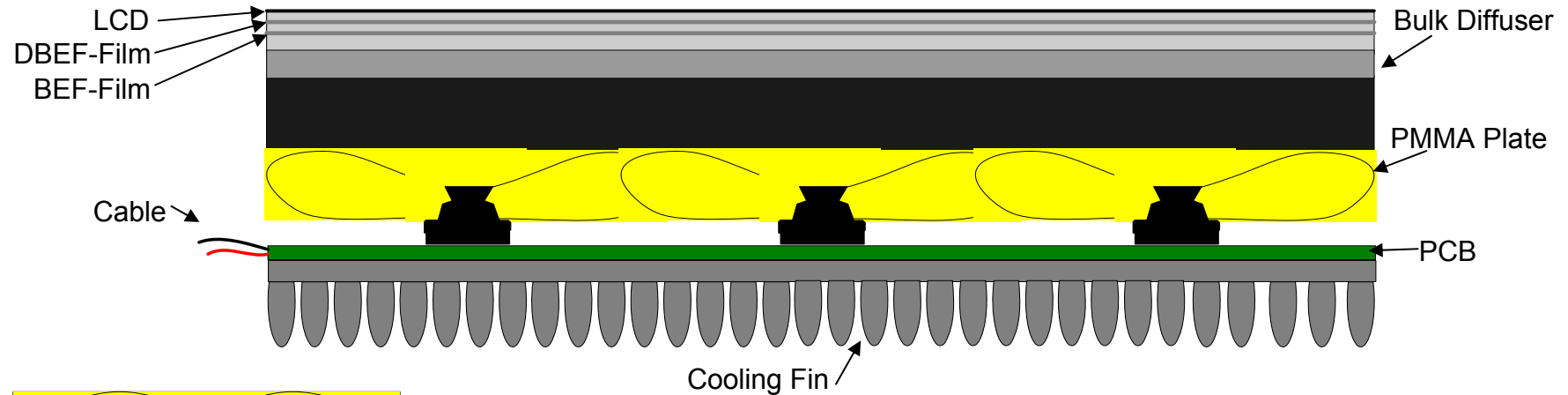


# LED – Light Intensity

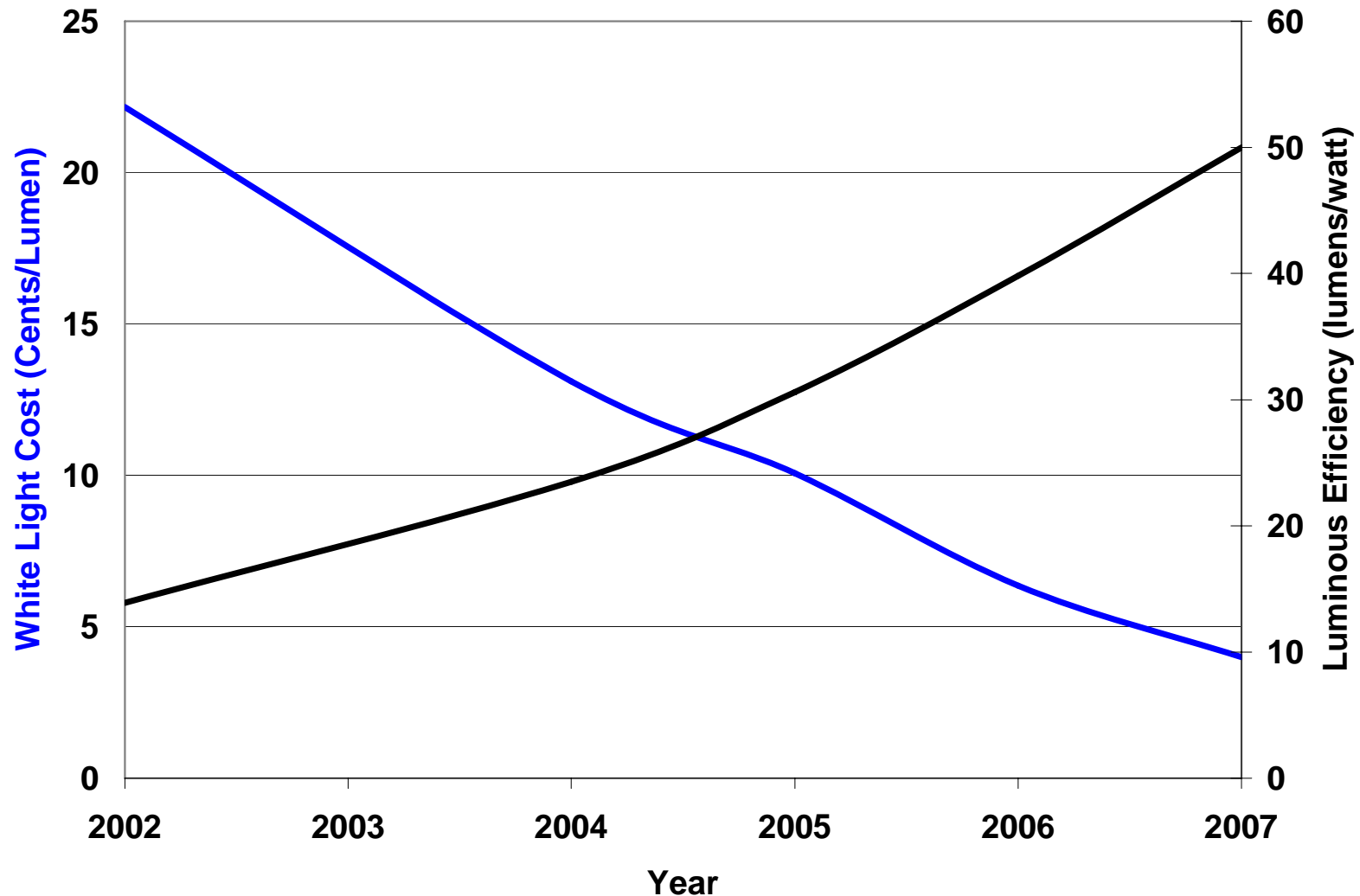




# LED – Backside



# White LED Trends





# Advantage vs Disadvantage

<i>Issue</i>	<i>CCFL</i>	<i>LED</i>	<i>Note</i>
Size	++	--	
Homogeneous of Luminance	+	-	
Dimmable	-	++	
Lifetime@-30°C	--	++	very good for automotive
Lifetime@0°C	+	++	
Lifetime@+25°C	++	+	
Lifetime@+60°C	++	--	
Lifetime@+85°C	++	---	very bad for automotive
Environmental	--	+	CCFL mercury is very low
Color Stabilization	++	+	
Brightness Stabilization	+	+	
Lost Temperature	++	-	For the same brightness
EMI	-	+	
Driving Voltage	--	+	
Useable for Ex-Protected Area	-	++	
Medicine Application	+	++	
Price of System	++	-	approx. +20%

# LED-Converter vs Resistor



## Examples for three HBLEDs with resistor

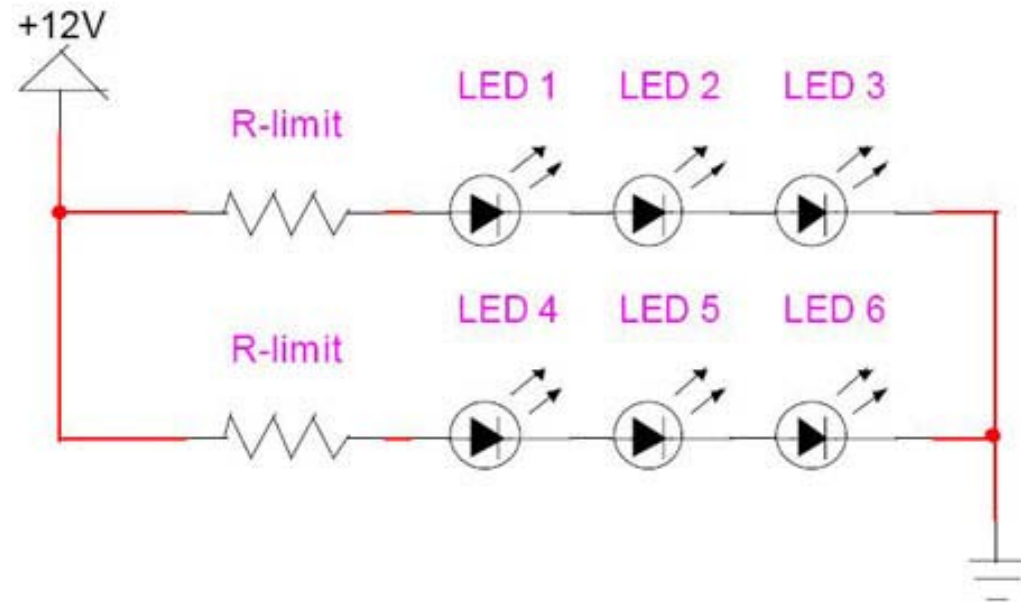
$$\begin{aligned} R\text{-limit} &= (V_{in} - (3 * V_{fwd})) / I_{fwd} \\ &= (12V - (3 * 3.0V)) / 0.5A \\ &= 6 \text{ ohms} \end{aligned}$$

$$\begin{aligned} P\text{-limit} &= I_{fwd}^2 * R\text{-limit} \\ &= 0.5^2 * 6 \\ &= 1.5 \text{ Watts} \end{aligned}$$

$$\begin{aligned} P \text{ LEDs} &= 3 * V_{fwd} * I_{fwd} \\ &= 3 * 3.0V * 0.5A \\ &= 4.5 \text{ Watts} \end{aligned}$$

$$\begin{aligned} \text{Efficiency} &= P_{LEDs} / (P_{LEDs} + P_{limit}) \\ &= 4.5W / (4.5W + 1.5W) \\ &= 75\% \text{ Not too impressive!} \end{aligned}$$

$$\begin{aligned} I_{fwd} &= (V_{in} - (3 * V_{fwd})) / R_{series} \\ &= (11.4V - (3 * 3.0V)) / 6 \text{ ohms} \\ &= 0.4 \text{ Amps} \end{aligned}$$



Delta **V<sub>in</sub>** = **+/-5% variation** of the +12V power supply will yield a **+/- 20% variation in LED** current — and therefore in LED brightness and life time. Of course, this variation could be reduced by increasing the voltage across the dropping resistor, but this would make the electrical efficiency only worse.



# LED-Converter vs Resistor

## Examples for three HBLEDs with Converter

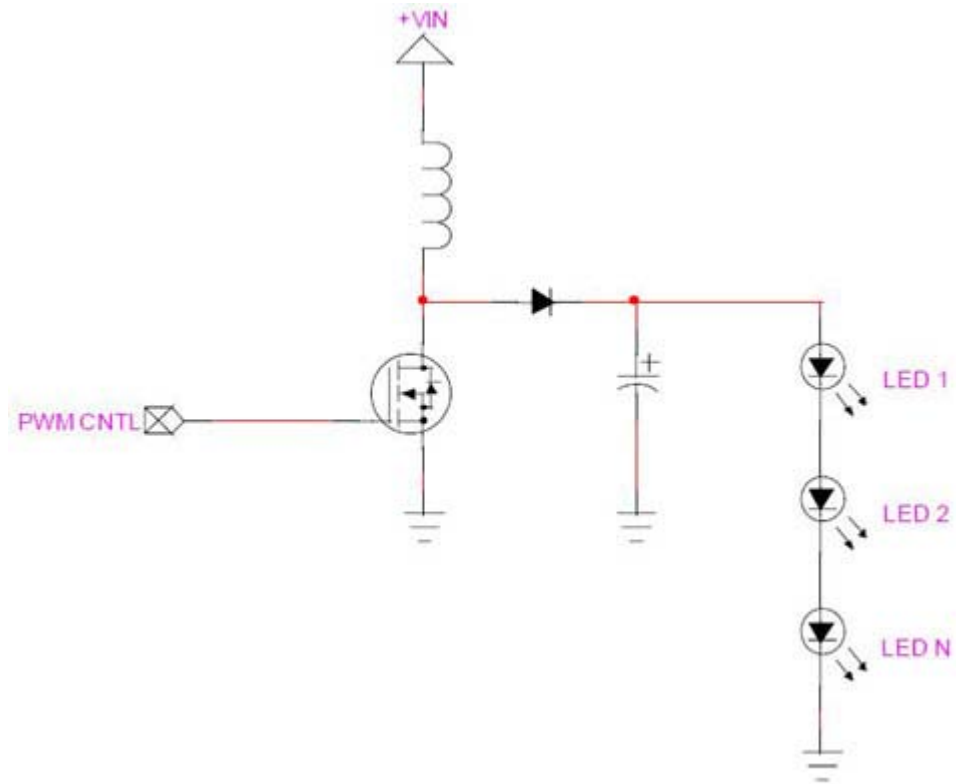
~~R-limit = (Vin - (3 \* Vfwd)) / Ifwd  
 = (12V - (3 \* 3.0V)) / 0.5A  
 = 6 ohms~~

~~P-limit = Ifwd<sup>2</sup> \* R-limit  
 = 0.5<sup>2</sup> \* 6  
 = 1.5 Watts~~

~~P LEDs = 3 \* Vfwd \* Ifwd  
 = 3 \* 3.0V \* 0.5A  
 = 4.5 Watts~~

**Efficiency = Converter**  
 = **>89% impressive!**

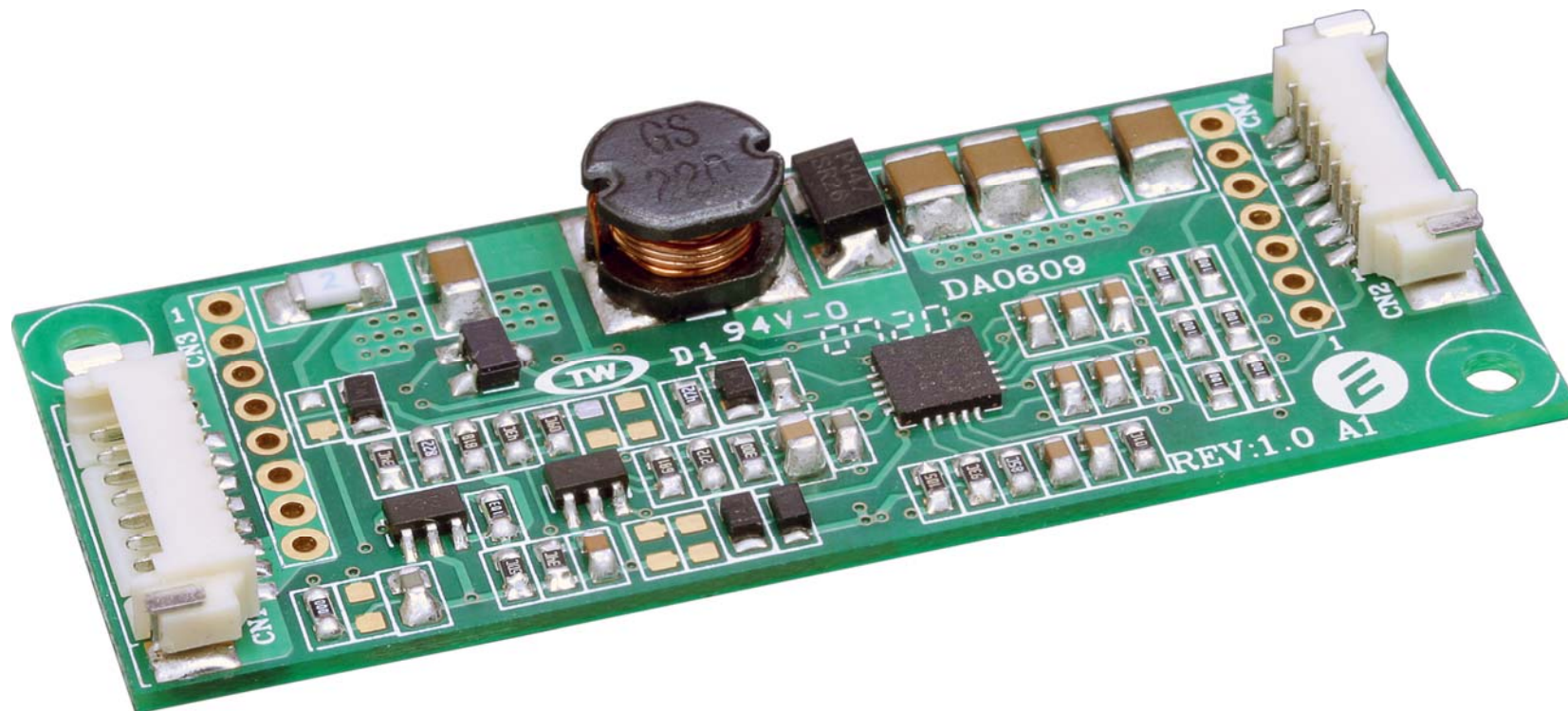
~~Ifwd = (Vin - (3 \* Vfwd)) / Rseries  
 = (11.4V - (3 \* 3.0V)) / 6 ohms  
 = 0.4 Amps~~



Delta Vin = +/-5% variation of the +12V power supply will yield a +/- 0% variation in LED current !!

# LED-Converter

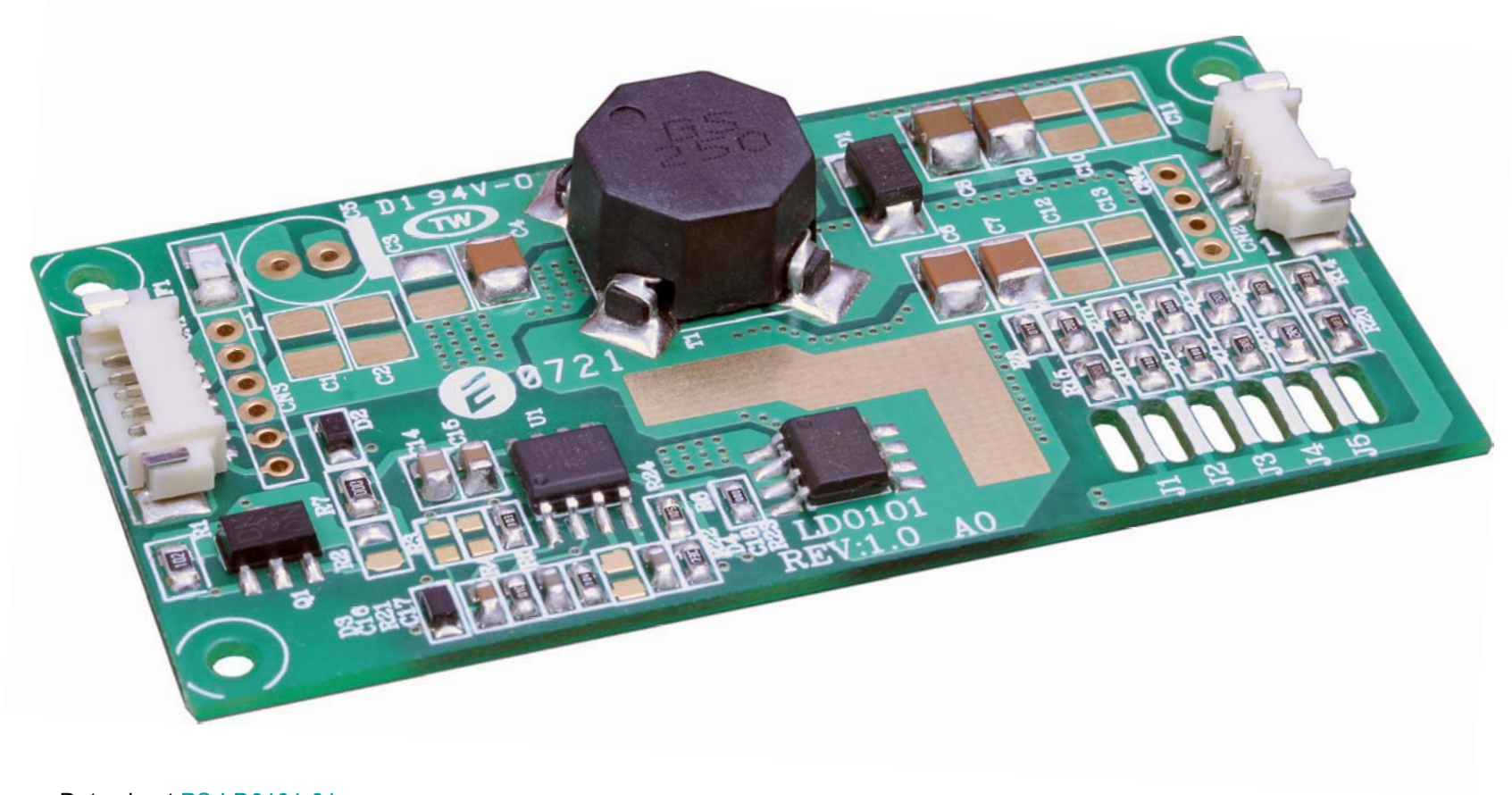
Power Systems Converter



Data sheet [PS-LD0609-01](#)

# LED-Converter

Power Systems Converter



Data sheet [PS-LD0101-01](#)

# Advantage vs Disadvantage



LED and CCFL will live in harmony together.  
Both technologies have advantages and disadvantages.  
Our all customer need to decide what they need and want.  
Our job is to explain them the technologies.

Good success.