The Nuts and Bolts of LEDs (LEDs 101)

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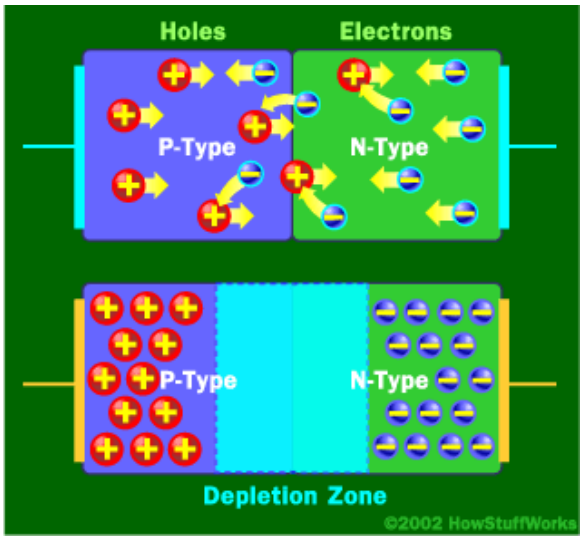
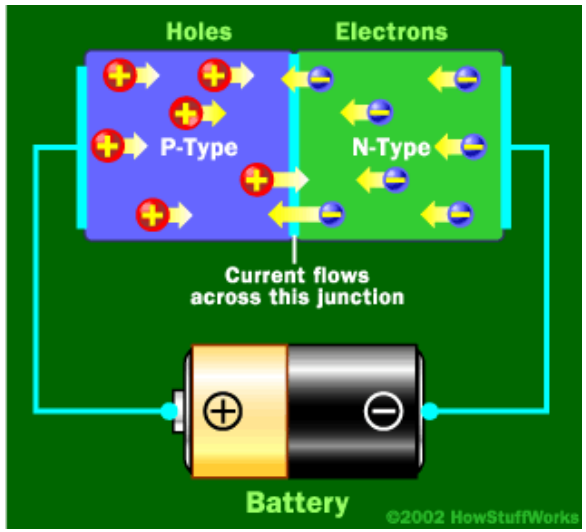
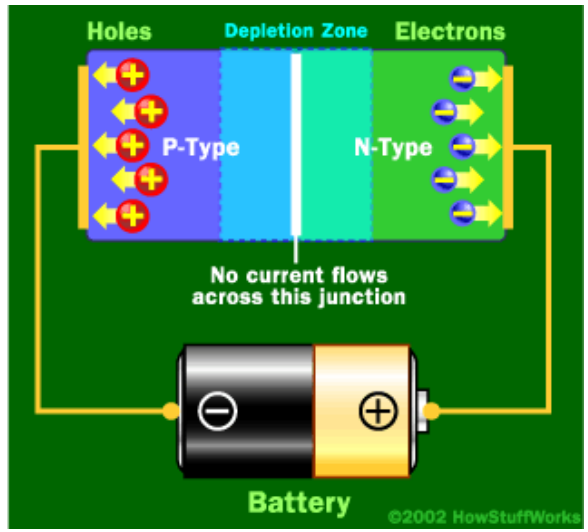
Outline

- **How do they work?**
- **Energy efficiency of white LEDs**
- **How do LEDs make white light?**
- **Color issues**
- **Effects of Heat**
- **Standards and test procedures**
  - **Life**
  - **Light Output**

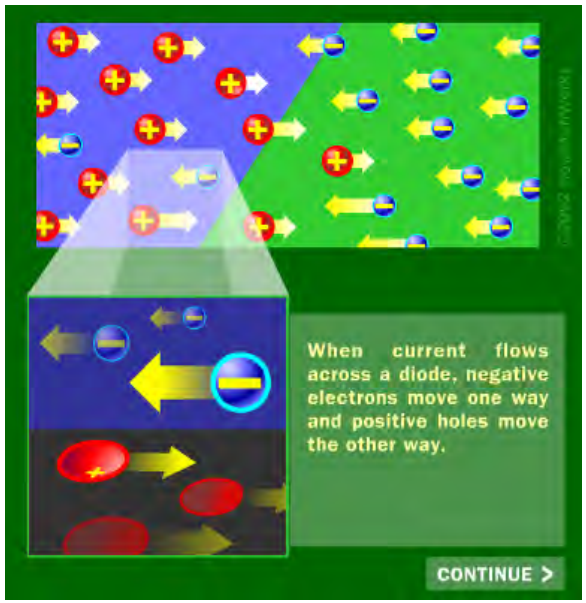
How does an LED Work?

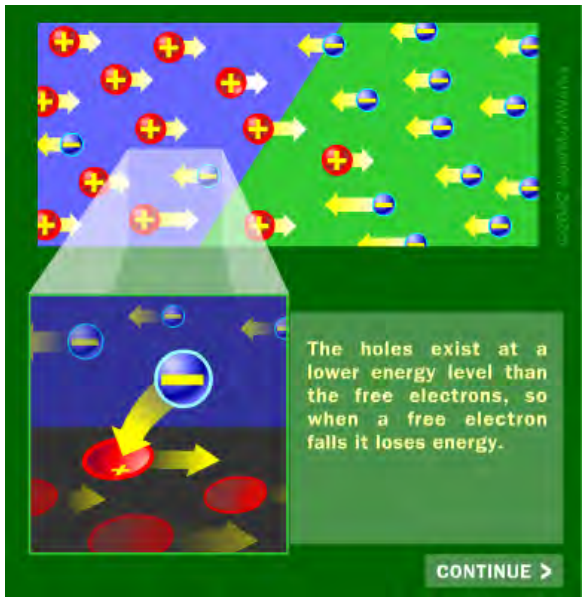


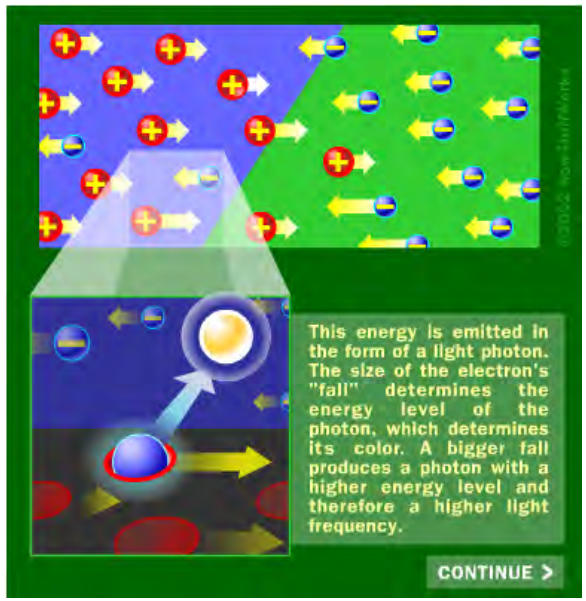




How does an LED make Light?

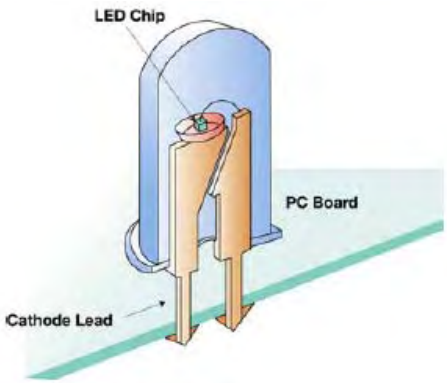




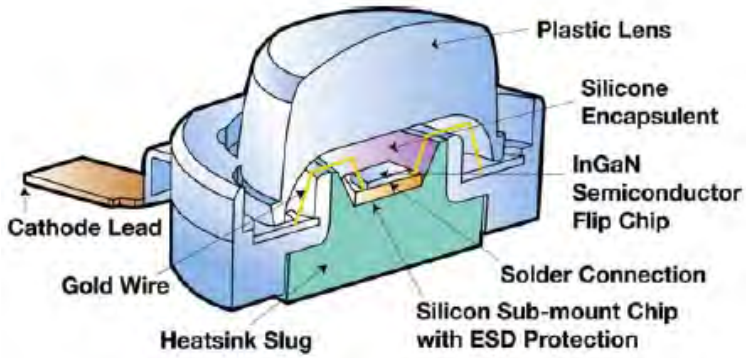


LED Types

Indicator

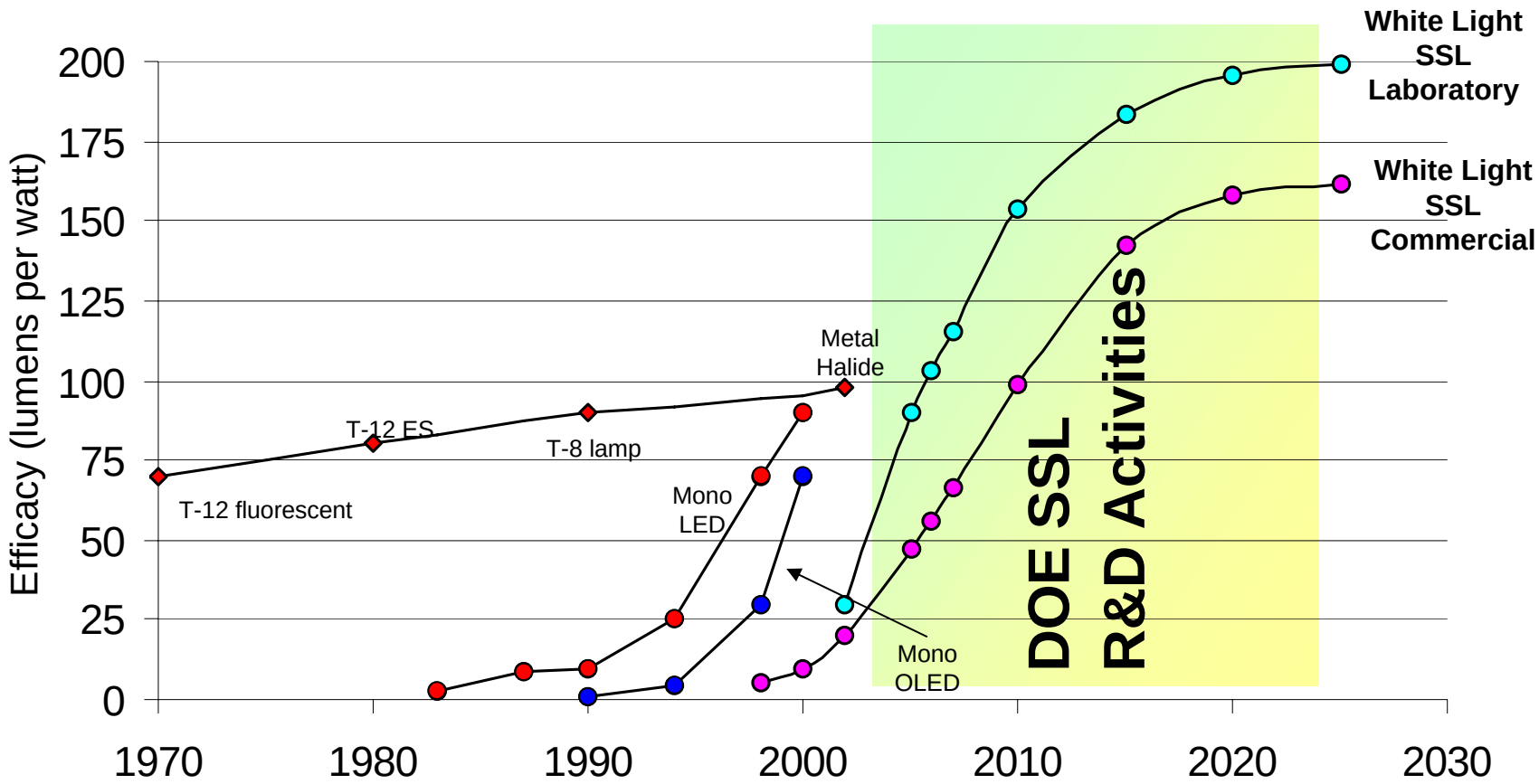


Illuminator



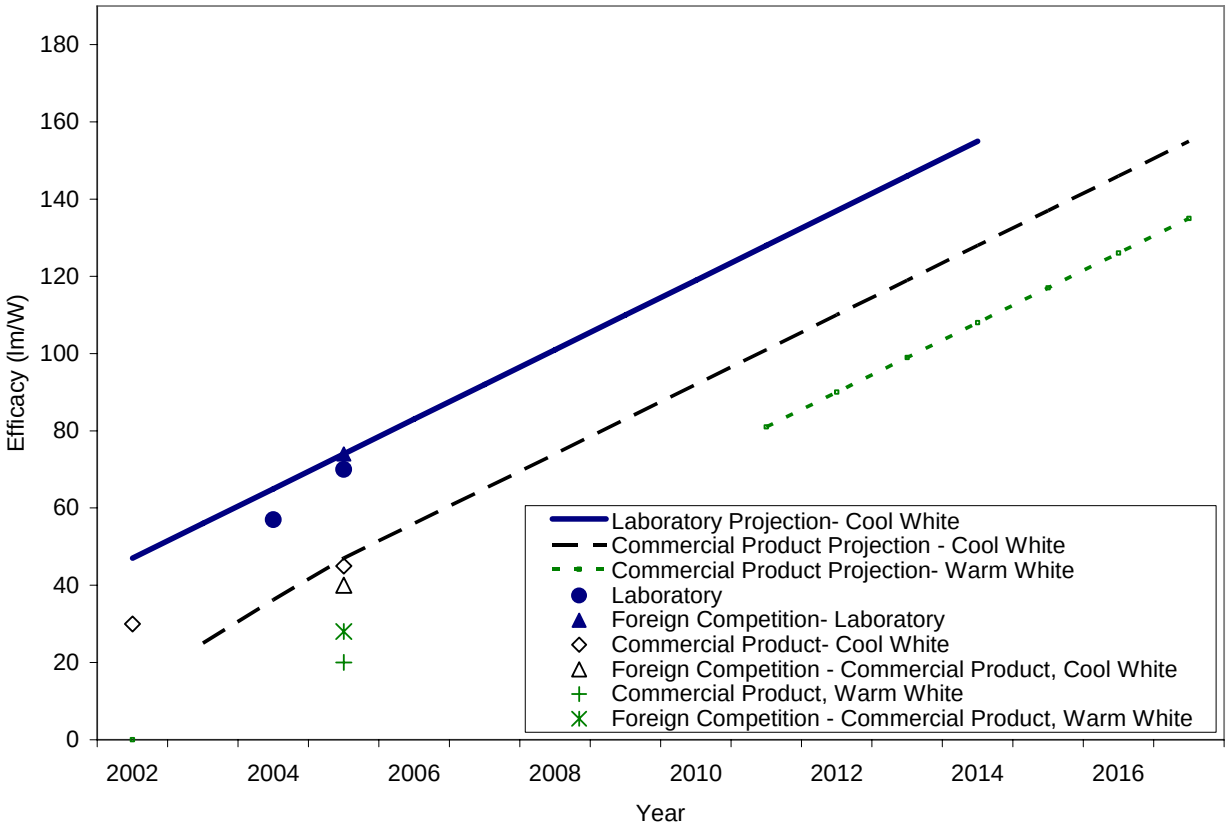
Courtesy: Lumileds

Accelerated R&D for White Light SSL



SSL Laboratory and Commercial Curves, revised September 2004

White-Light LED Efficacy Targets



Note: Efficacy projections assume CRI=70 → 80, Color temperature = 5000-6000°K, 350ma drive current, and lamp-level specification only (driver/luminaire not included), reasonable lamp life.

Efficiency and Cost of White-Light Sources

Source efficacy (2006)

- Incandescent (75W) ~13 lm/W
- Fluorescent (T8) ~83 lm/W
- HID (Metal Halide) ~100 lm/W
- SSL (White LED) ~50 lm/W

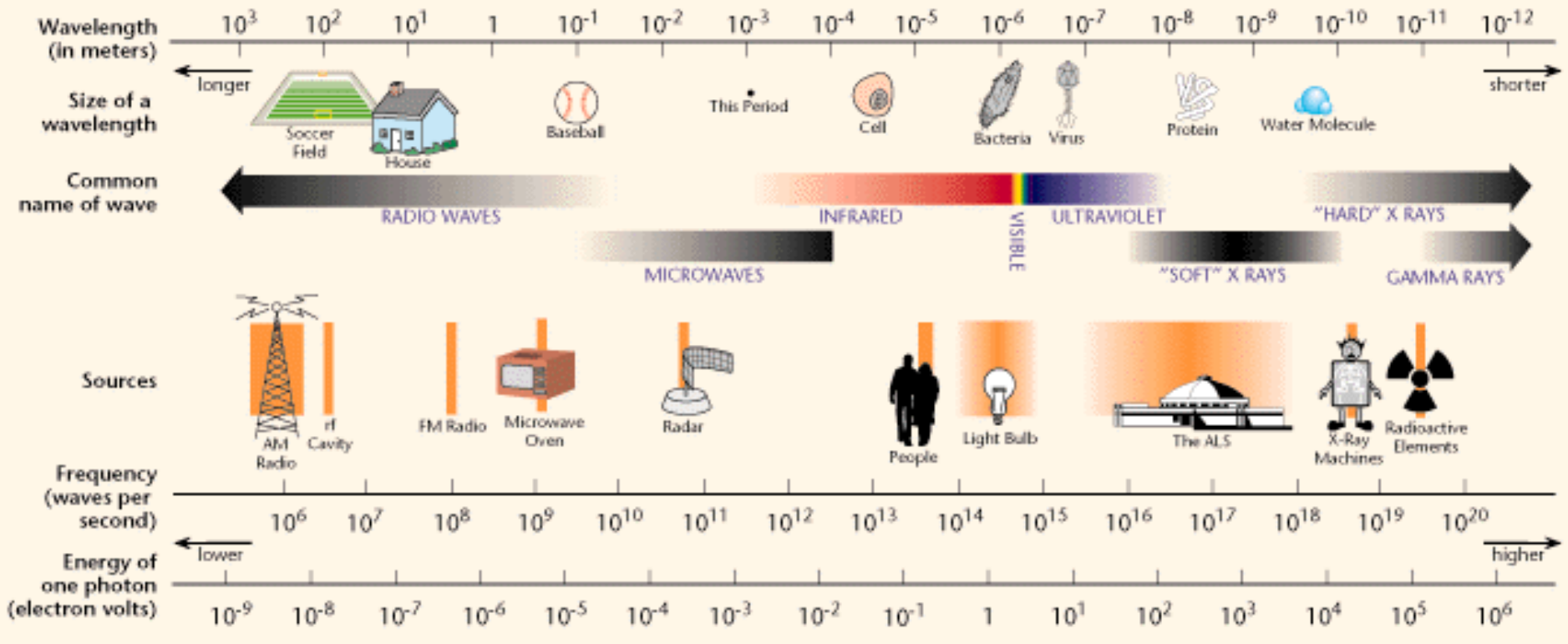
Normalized retail lamp price (2006)

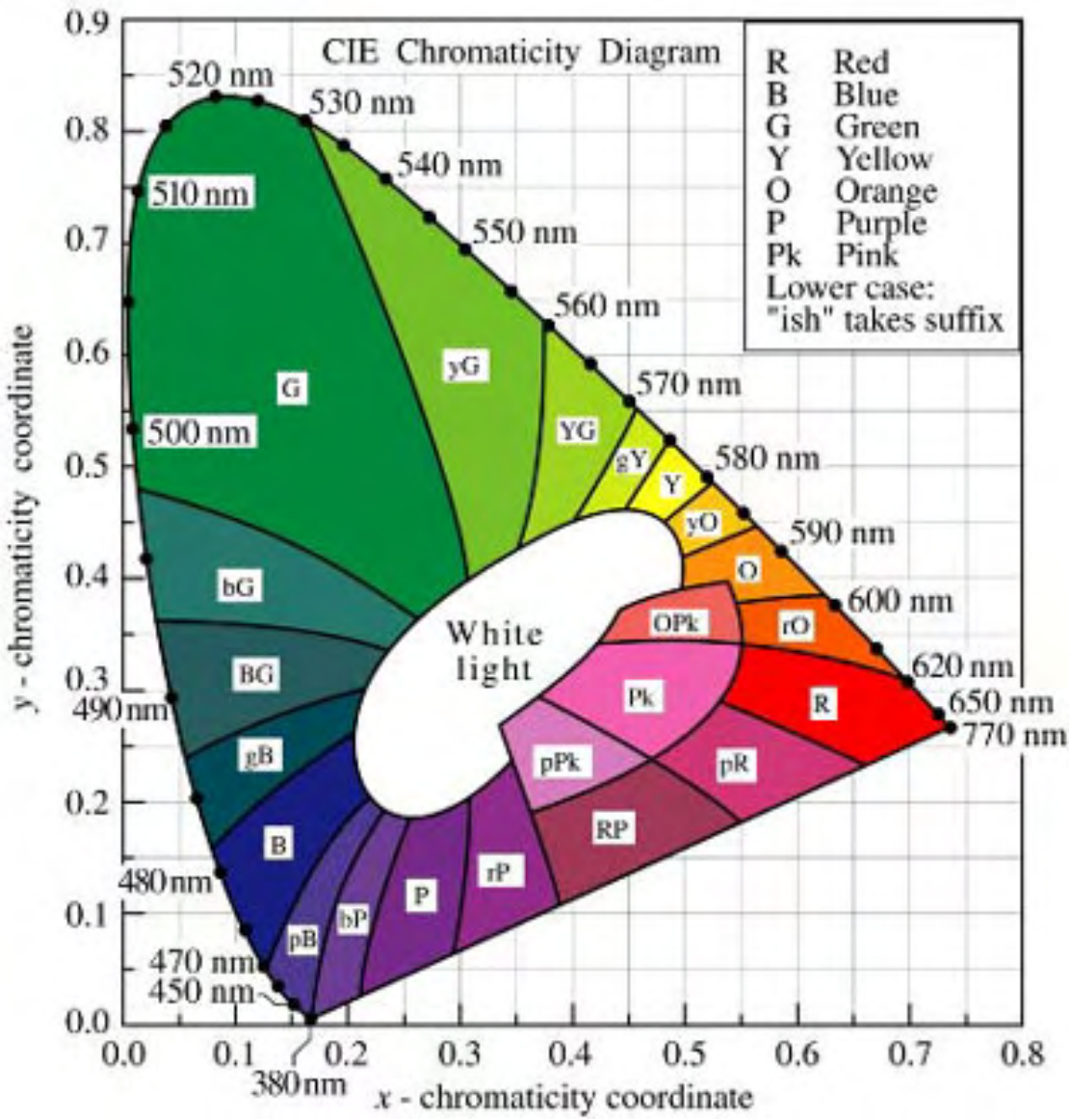
- Incandescent (75W) ~0.60 $/klm
- Fluorescent (T8) ~0.73 $/klm
- HID (Metal Halide) ~1.27 $/klm
- SSL (White LED) ~50.00 $/klm

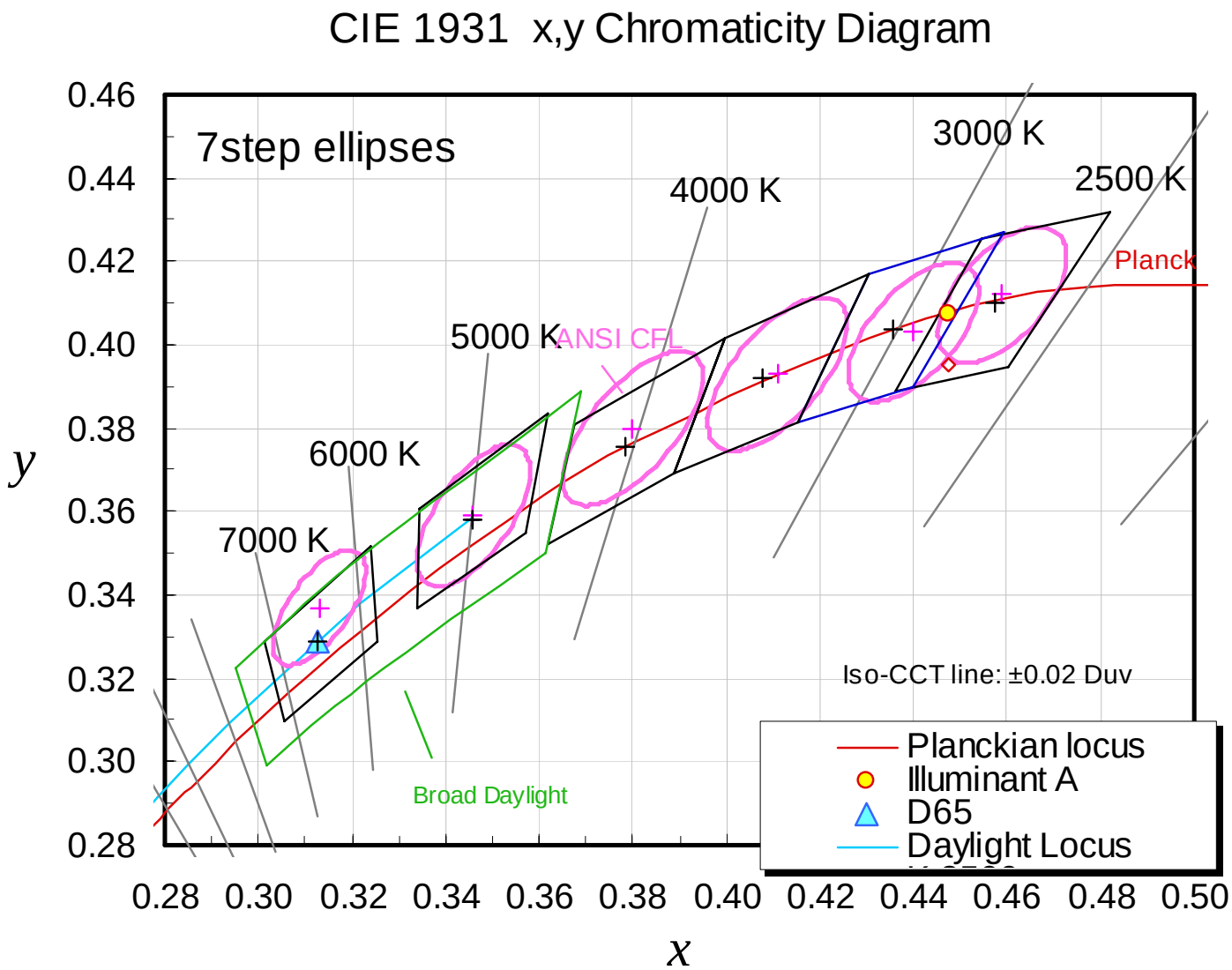
*manufacturer data

Research is improving SSL efficacy while decreasing price

THE ELECTROMAGNETIC SPECTRUM

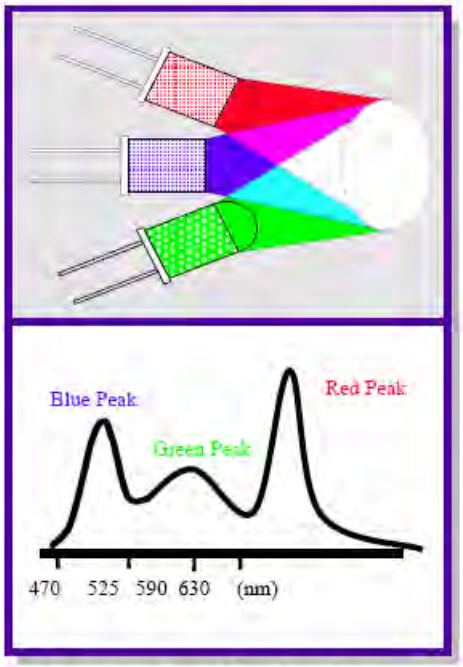



CIE Chromaticity Diagram
R Red
B Blue
G Green
Y Yellow
O Orange
P Purple
Pk Pink
Lower case:
"ish" takes suffix
520 nm
530 nm
540 nm
550 nm
560 nm
570 nm
580 nm
590 nm
600 nm
620 nm
650 nm
770 nm
510 nm
500 nm
490 nm
480 nm
470 nm
450 nm
380 nm
G
yG
YG
gY
Y
yO
O
rO
R
OPk
Pk
pPk
pR
RP
rP
P
bP
pB
B
gB
BG
bG
White light
y - chromaticity coordinate
x - chromaticity coordinate
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9


CIE 1931 x,y Chromaticity Diagram
7step ellipses
3000 K
2500 K
4000 K
Planck
5000 K
ANSI CFL
6000 K
7000 K
Iso-CCT line: ±0.02 Duv
Broad Daylight
Planckian locus
Illuminant A
D65
Daylight Locus
0.46
0.44
0.42
0.40
0.38
0.36
0.34
0.32
0.30
0.28
y
0.28 0.30 0.32 0.34 0.36 0.38 0.40 0.42 0.44 0.46 0.48 0.50
x

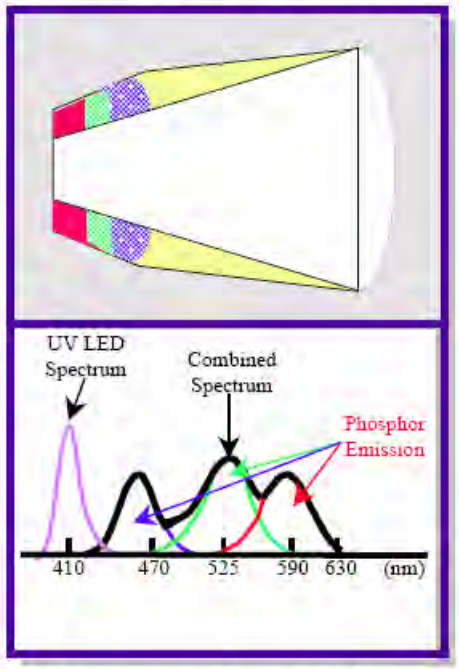
Methods to Create White Light

Red + Green + Blue LEDs



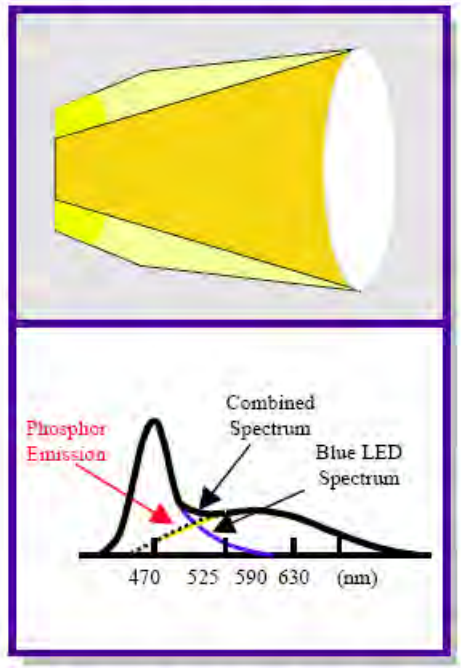
- Dynamic color tuning
- Excellent color rendering
- Large color gamut

UV LED + RGB Phosphor



- White point tunable by phosphors
- Excellent color rendering
- Simple to create white

Blue LED + Yellow Phosphor



- Simple to create white
- Good color rendering

Courtesy: Lumileds

White Light SSL Challenges

- **Lifetime – lumen maintenance, heat management**
- **Efficacy – improving rapidly**
- **Color Quality**
- **Luminous Flux**
- **Cost**
- **Standards and test procedures**
- **Ready or Not**

Color Quality Issues

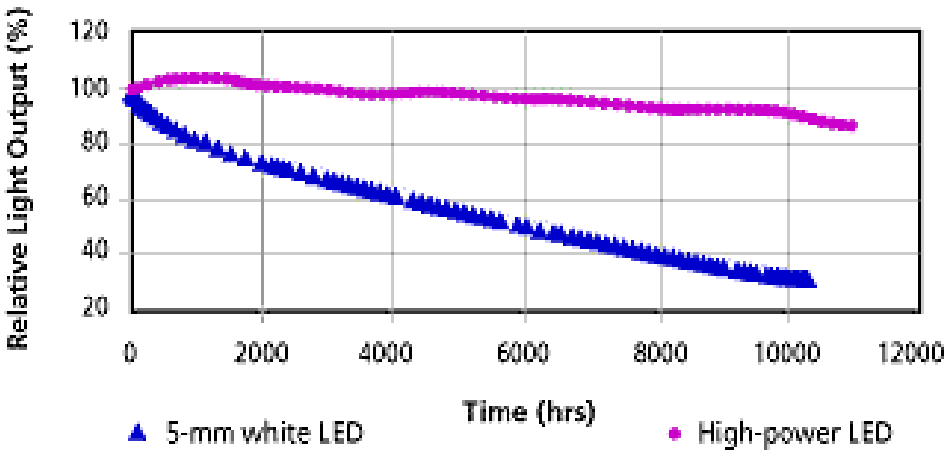
- **Correlated color temperature (CCT)**
  - **Color appearance of white light**
  - **High CCT sources look "cooler" and bluer**
  - **Low CCT sources look "warmer" and more yellow**
  - **Higher efficacy LEDs typically have high CCT**
- **Color consistency**
  - **Different color appearance within shipments of white LEDs**
  - **Color shifts over time with LED degradation**
- **Color rendering index (CRI)**

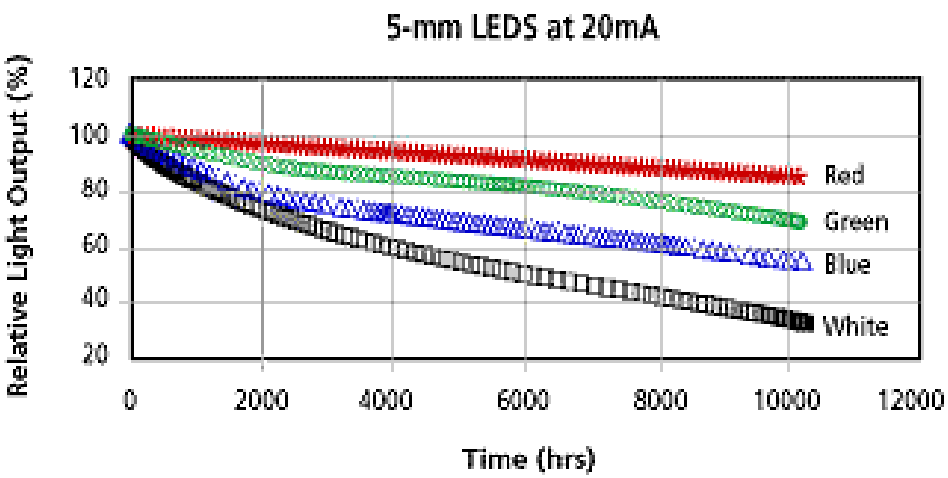
Efficiency & Quality Trade-offs

Color Temperature*	↑	Efficacy	↑
Color Temperature*	↓	Efficacy	↓
CRI*	↑	Efficacy	↓
Heat	↑	Efficiency / Output	↓
Heat	↑	Life / Durability	↓

* Phosphor-converted LEDs

Light Output for LED types





Courtesy of LRC

So you thought LEDs don't create heat?

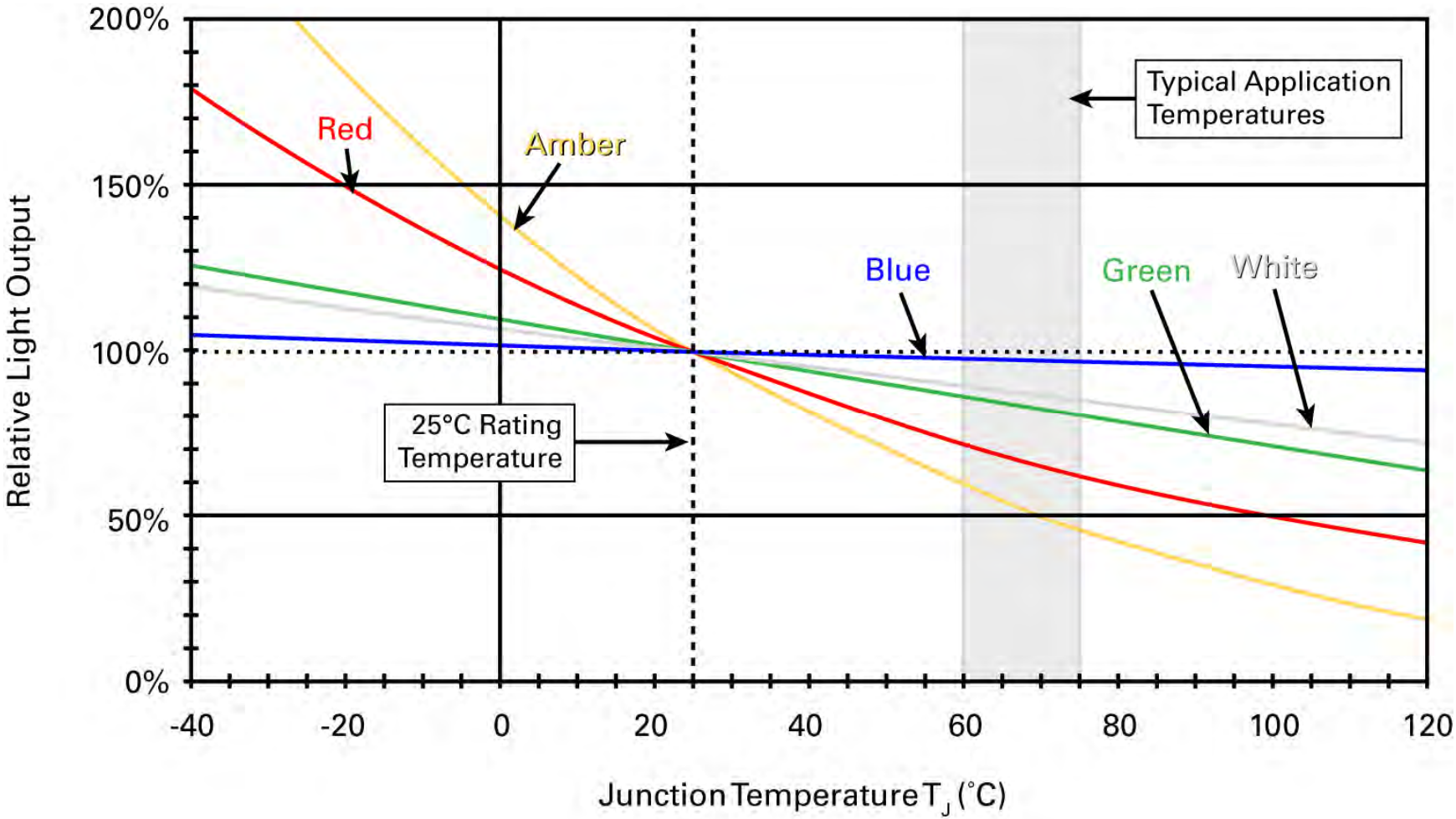
Power Conversion for "White" Light Sources

	Incandescent† (60W)	**Fluorescent**† (Typical linear CW)	**Metal Halide**‡	**LED**
Visible Light	7.5 %	21 %	27 %	10-15 %
Infrared	73.3 %	37 %	17 %	~ 0 %
Ultraviolet	0 %	0 %	19 %	0 %
Total Radiant Energy	80.8 %	58 %	63 %	10-15 %
Heat (Conduction + Convection)	19.2 %	42 %	41 %	85-90 %
Total	100 %	100 %	100 %	100 %

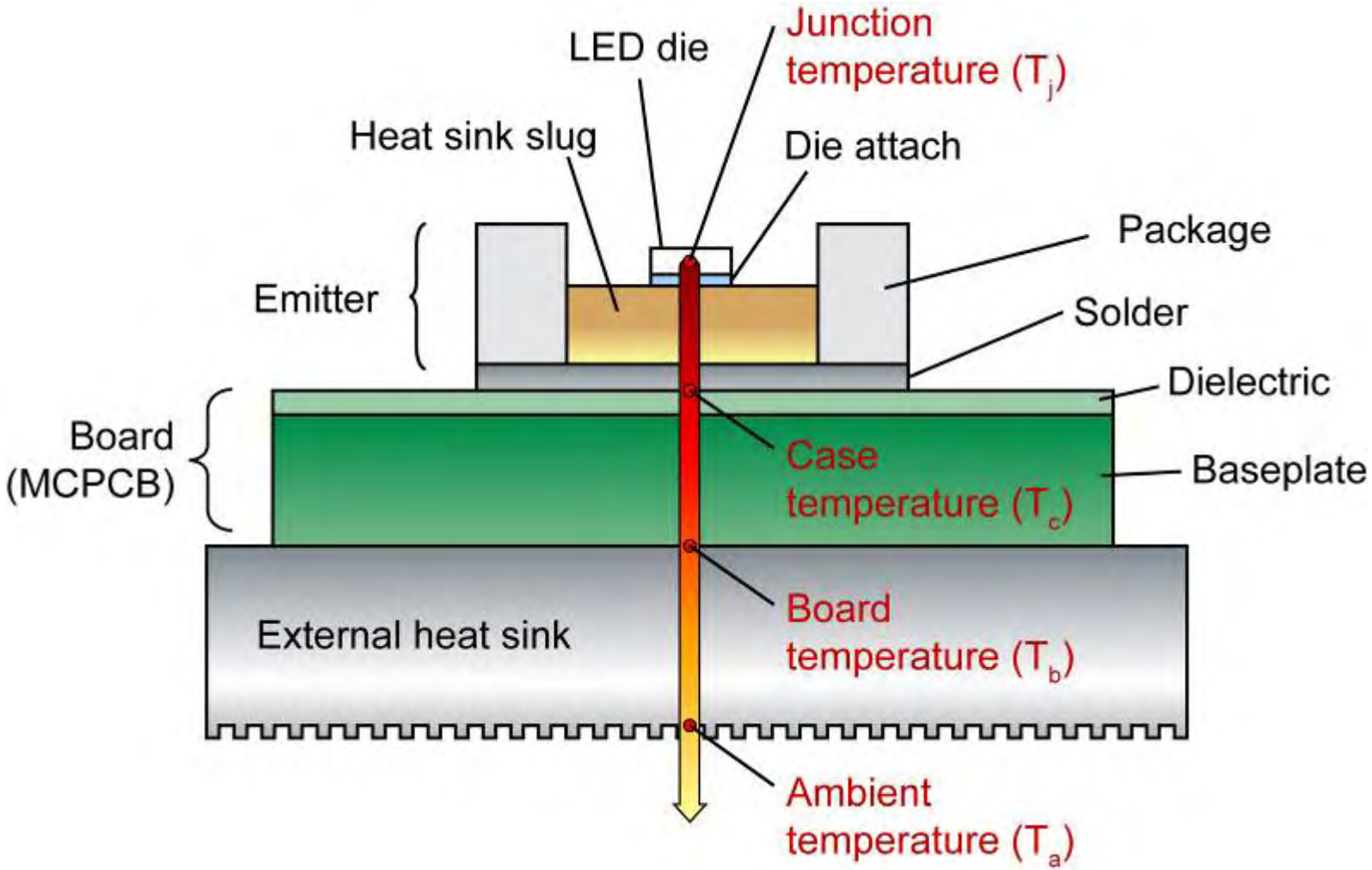
† IESNA Lighting Handbook – 9th Ed.

‡ Osram Sylvania

Light Output vs. Junction Temperature (T_j)



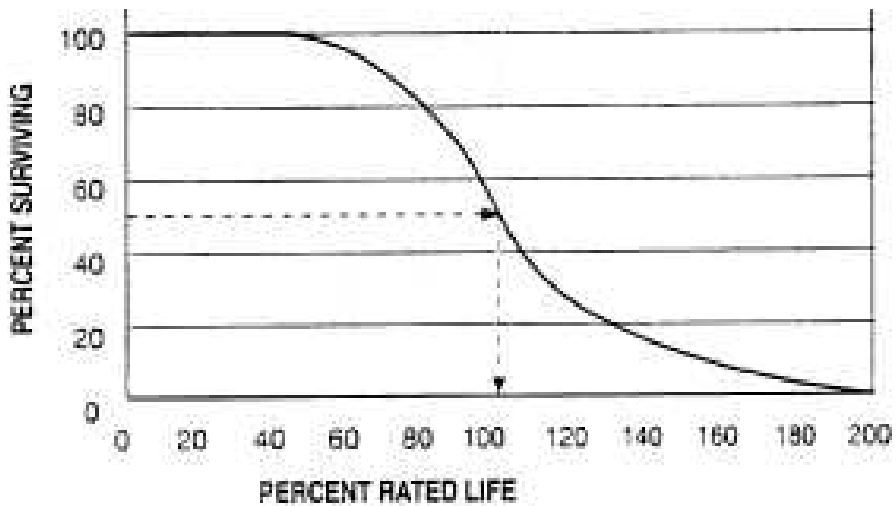
What Effects Junction Temperature?



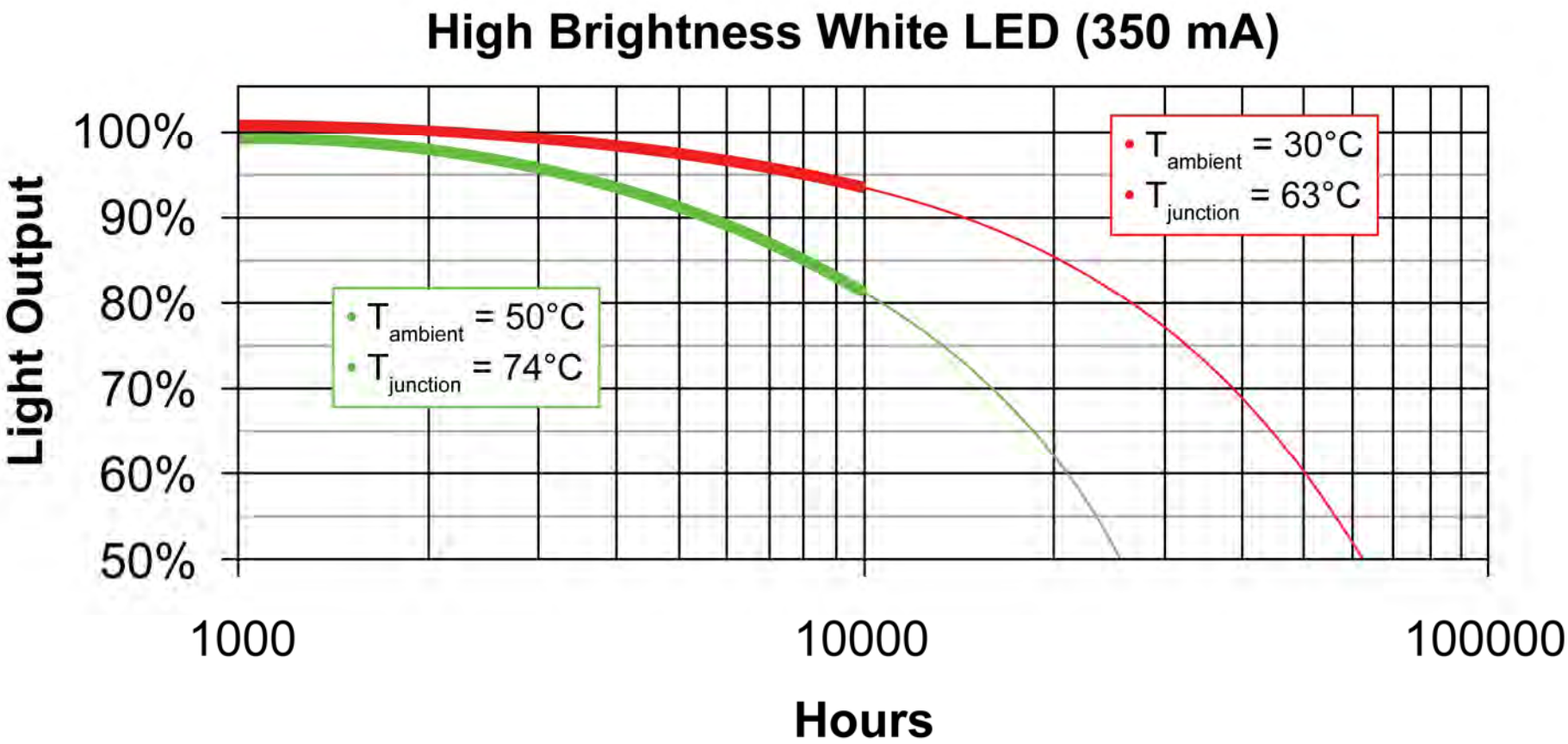
Life Rating

- **Lumen depreciation vs. failure**
- **LED life definition may differ by application**
  - **L_{70} for general illumination**
  - **L_{50} for indication**
  - **L_{80} for some applications?**
- ***ASSIST recommends* proposed method**

Typical lamp mortality curve



Temperature Effects on Life



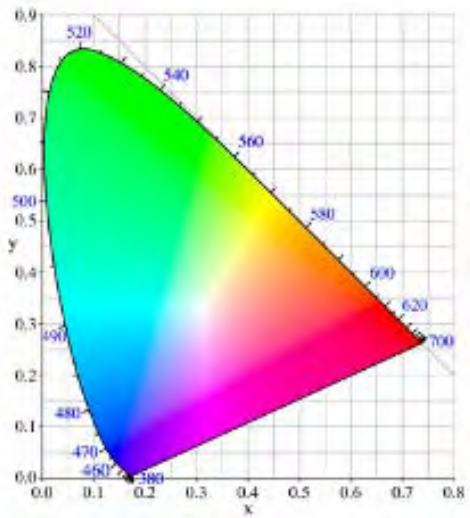
Courtesy of LRC

Standards and Test Procedures

- **DOE hosted Mar 1 workshop in DC**
- **Standards groups working to the ENERGY STAR schedule**
- **DOE providing on-going technical support for standards development**

Standards and Test Procedures

- **Test procedures under development**
  - **Photometric measurements (IESNA LM-79)**
  - **Life-testing (IESNA LM-80)**
  - **Chromaticity (ANSI C78.XX1)**
  - **Electrical measurements (ANSI C78.XX3)**
  - **Definitions (ANSI C78.XX2)**
- **Final procedures expected in May 2007**



More Information

http://www.netl.doe.gov/ssl/

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