Lighting Research Center at Rensselaer

SARI / Energy

Overview of Recent Technology Trends in Energy-Efficient Lighting

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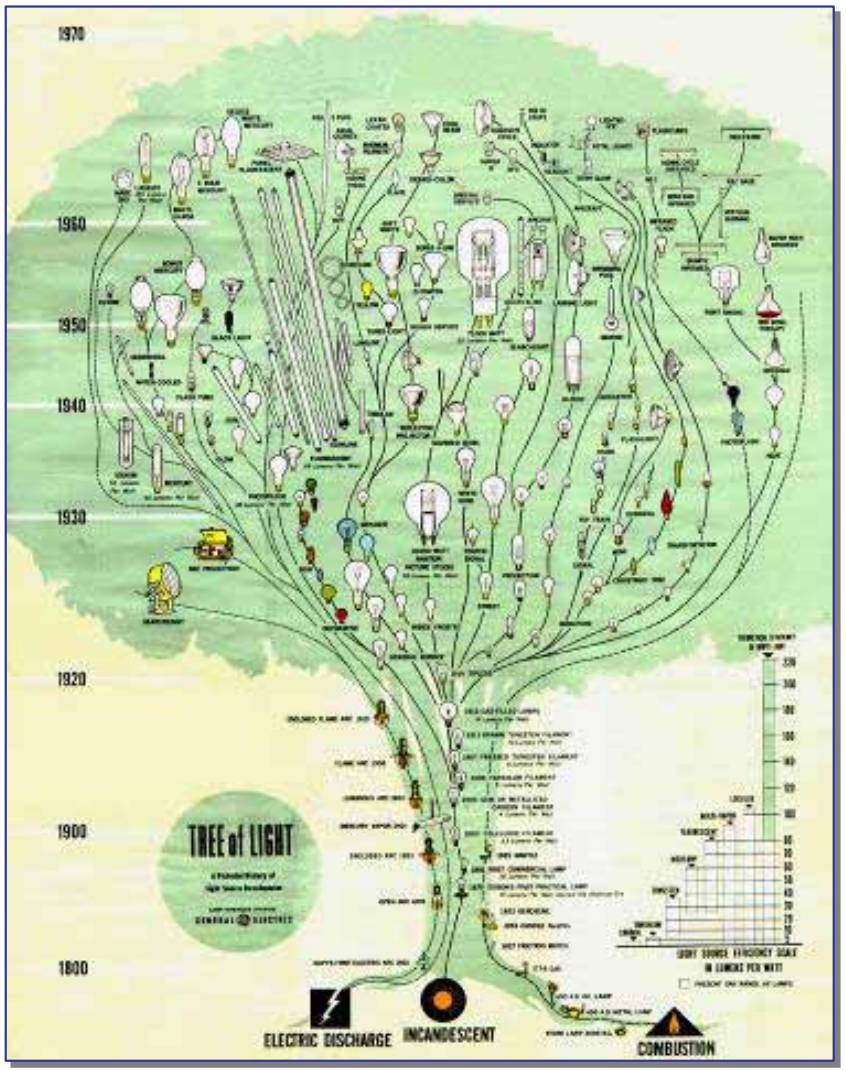
Electric lighting history

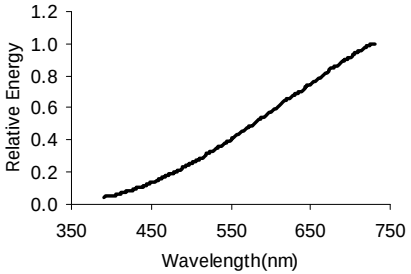
- In 1879, Thomas Alva Edison demonstrated the first successful light bulb.

- Over the past 125 years, incandescent and gas discharge technologies have provided many shapes and sizes of light sources for a variety of lighting applications.

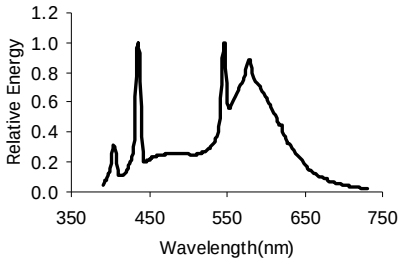


Light source technologies

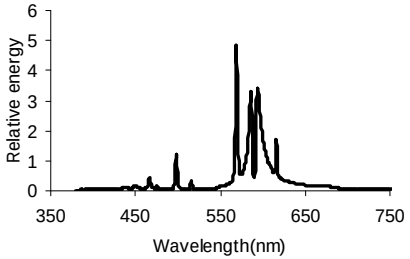
Incandescent



Fluorescent



High Pressure Sodium

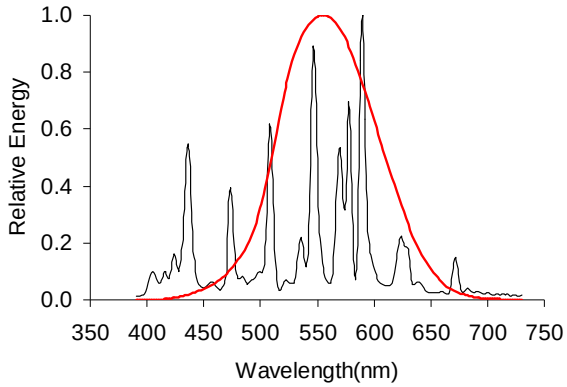


Spectral power distribution (SPD)

my.dteenergy.com/products/images/roadway1.jpg

Luminous flux and efficacy

- Lumen and lumens per watt are two key metrics commonly used in the lighting industry to quantify performance of light sources.



- Lumen: The luminous flux accounts for the sensitivity of the eye by weighting the radiant power at each wavelength with the human eye response function.

$$\text{Flux } (\Phi) = 683 \int S_\lambda V_\lambda \, d\lambda \text{ (lm)}$$

- Lumens per watt: Luminous efficacy of a light source is the total luminous flux emitted by the lamp divided by the total lamp power (electrical) input.

$$\text{Efficacy} = \Phi / W \text{ (lm/W)}$$

Light source technologies

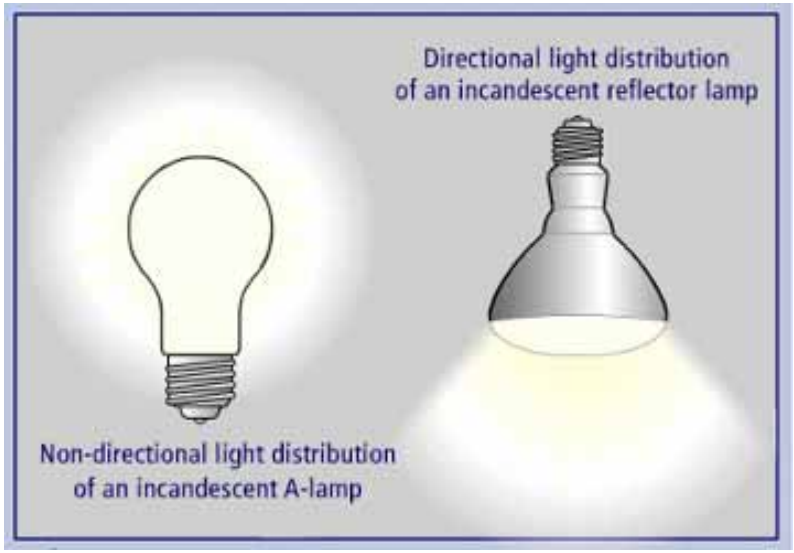
- Incandescent light sources range in efficacy from 2 to 20 lm/W.

- Fluorescent light sources range in efficacy from 25 to 105 lm/W.

- High-intensity light sources range in efficacy from 25 to 150 lm/W.

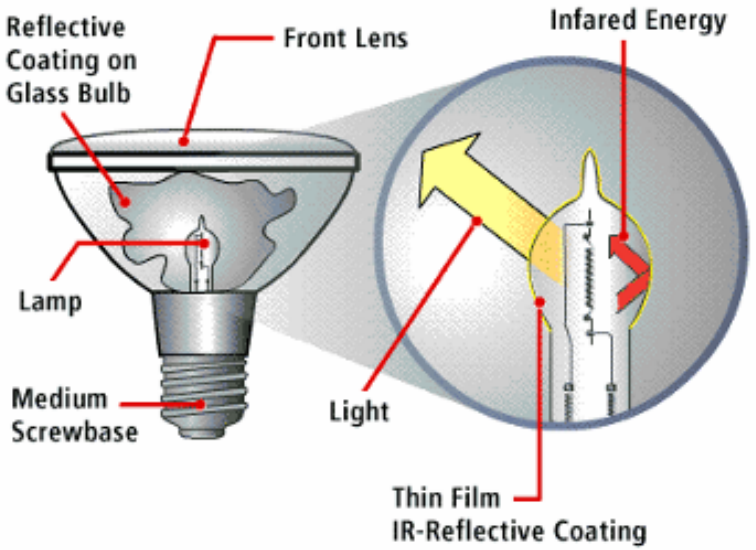
Incandescent

- Filament heating produces light
  - Only 5% of the total energy input is converted to light and the rest is heat
  - Very inefficient
- Efficacy
  - Generally around 15 lm/W
- Color
  - CRI = 95+
  - CCT = 2500K – 3000K
- Life (average rated)
  - 750 – 2000 hours
  - Dimming can extend life



Halogen

- A halogen lamp contains an inert gas and a small amount of halogen.
  - The filament can operate at higher temperatures than a standard gas filled lamp without shortening its operating life. This gives it a higher efficacy (10-30 lm/W).
  - Higher color temperature compared to a non-halogen incandescent lamp.
- Efficacy
  - PAR and MR Lamps (line or low voltage)
    - ✓ 10 to 25 lm/W
  - IR PAR Lamps (Infrared reflector)
    - ✓ 20 to 30 lm/W
- Color
  - CRI – 95+
  - CCT – Typically 3000K
- Life (average rated)
  - 2000 hours
  - Shortens if consistently dimmed below 80%

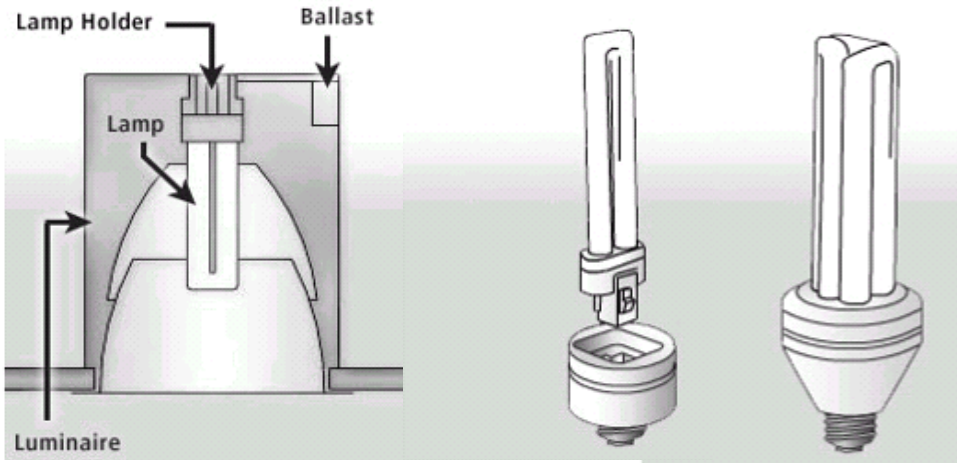


Fluorescent

- A fluorescent lamp is a low-intensity gas-discharge lamp that uses electricity to excite mercury vapor to produce ultraviolet (UV) radiation that causes a phosphor to fluoresce and produce light.
  - It does not use heat to produce light; therefore, it is more efficient than incandescent.
  - Linear fluorescent lamps (LFL) and compact fluorescent lamps (CFL) are popular choices for conserving energy.
  - About 20% to 30% of the total energy input is converted to light.

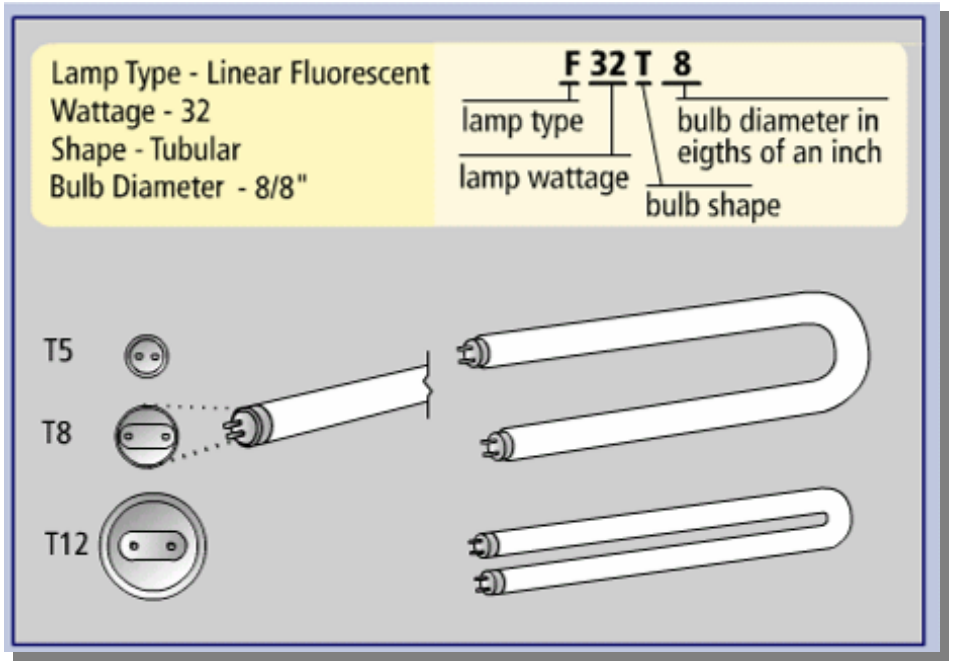
Compact fluorescent lamp (CFL)

- Types:
  - Pin-base for dedicated fixtures
  - Screw-base self-ballasted
- Efficacy:
  - 25 to 60 lm/W
- Color
  - CRI = 82 typical
  - CCT = 2700K, 3000K, 3500K, 4100K, 5000K
- Life
  - 6,000 to 10,000 hours
    - ✓ Frequent on-off switching can reduce life significantly
    - ✓ Dimming is possible but can reduce life



Linear fluorescent lamp (LFL)

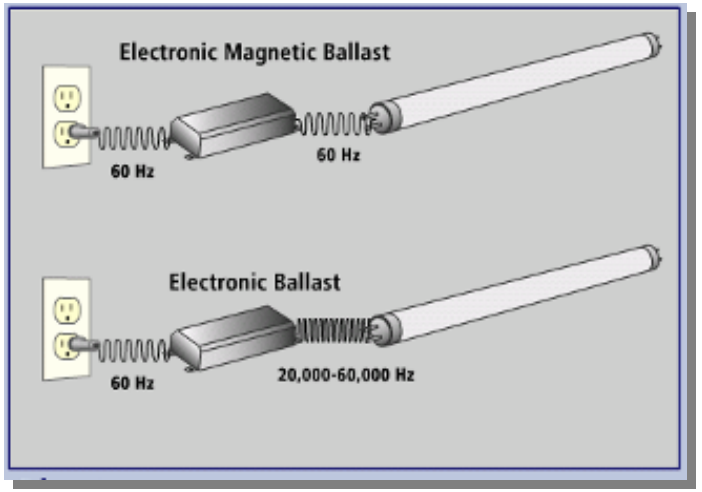
- Lamp Efficacy
  - Ranges from 65 to 105 lm/W
- Color
  - CRI = 82 typical
  - CCT = 2700K, 3000K, 3500K, 4100K, 5000K
- Life
  - 20,000 to 30,000 hours
    - ✓ Frequent on-off switching can reduce life significantly
    - ✓ Dimming can reduce life



Type	Rated Power (watts)	Light Output (lumens)	Efficacy (lumens/watt)
T5 Linear	35	3650	104.3
T8 Linear	32	2850	89.1
T12 Bent	40	2800	70

Ballasts for LFL

- Fluorescent lamps require a ballast to operate
  - Magnetic
    - ✓ Low frequency (60 Hz) operation
    - ✓ May produce audible hum
    - ✓ May produce noticeable lamp flicker
    - ✓ Inefficient lamp operation



  - Electronic
    - ✓ High frequency (20 to 60 kHz) operation
    - ✓ Quiet
    - ✓ No noticeable lamp flicker
    - ✓ More efficient lamp operation

Electronic ballasts for LFL

- Instant start
  - Most efficient type
  - May sacrifice lamp life if frequently switched
  - Difficult to dim
- Rapid start and programmed start
  - Generally consumes an additional 2 watts
  - More gentle starting for frequent switching
  - Can be dimmed (if a dimming ballast is selected)

High intensity discharge (HID)

- Metal halide lamps produce light by passing an electric arc through a mixture of gases, which causes a metallic vapor to produce radiant energy.
  - It contains a high-pressure mixture of argon, mercury, and a variety of metal halides in a compact arc tube.
  - About 24% of the total energy input is converted to light.

- Three types of HID lamps:
  - Mercury vapor lamp: Relatively low efficacy, poor color rendering properties, but very long service life. Bluish tint light.
  - Metal halide lamps: High efficacy, good color rendition, long service life, but poor lumen maintenance. Extensively used in outdoor applications and in commercial interiors.
  - High-pressure sodium (HPS) lamp: Very high efficacy and long life (~24,000 hrs). Yellow tinted light and poor color rendering properties. Predominantly used in outdoor applications.

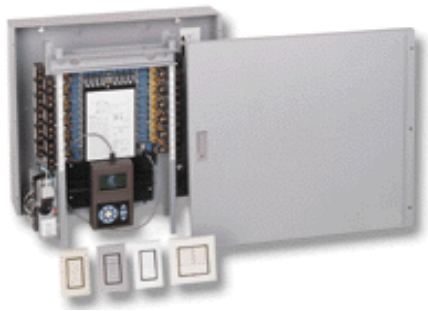
Ballasts for HID

- Metal halide lamps require ballasts to regulate the arc current flow and deliver the proper voltage to the arc.
  - **Probe-start metal halide:** Contains a starting electrode within the lamp to initiate the arc when the lamp is first lit.
  - **Pulse-start metal halide:** No starting electrode but has a special starting circuit to generate a high-voltage pulse to the operating electrodes.

Lighting controls

- Manual controls
  - Wall switch: on or off
  - Dimmers

- Automatic controls
  - Time clocks
  - Occupancy sensors
    - ✓ Infrared
    - ✓ Ultrasonic
    - ✓ Dual technology
  - Panel relays
  - Centralized controls



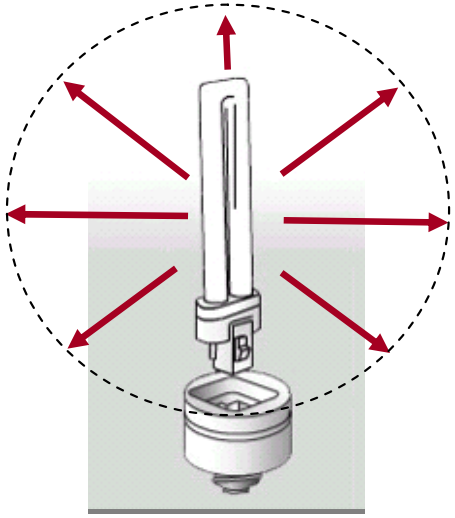
Efficacy and energy savings

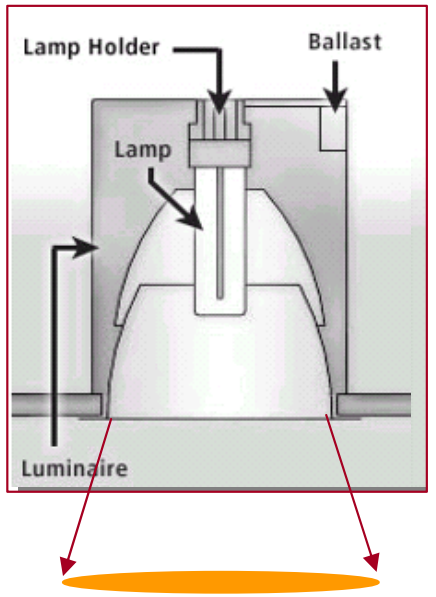
- Energy use depends on the connected load and time of use
  - Watt-hours

- **MYTH:** High efficacy light sources always save more energy than low efficacy light sources.
  - Spatial – light not reaching the application area is wasted light (energy)
  - Temporal – light beyond the required time is wasted light (energy)

Different forms of luminous efficacy

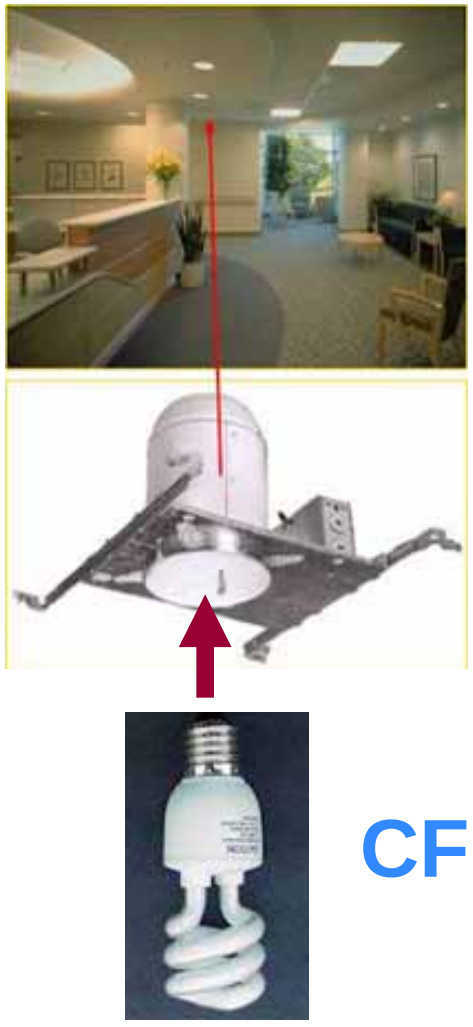
- **Light source (lamp) efficacy:** Total lumens out of the light source divided by the total input power to the light source
- **Light source + ballast efficacy:** Total lumens out of the light source divided by the total input power to the ballast
- **Luminaire efficacy:** Total lumens exiting the luminaire divided by the total input power

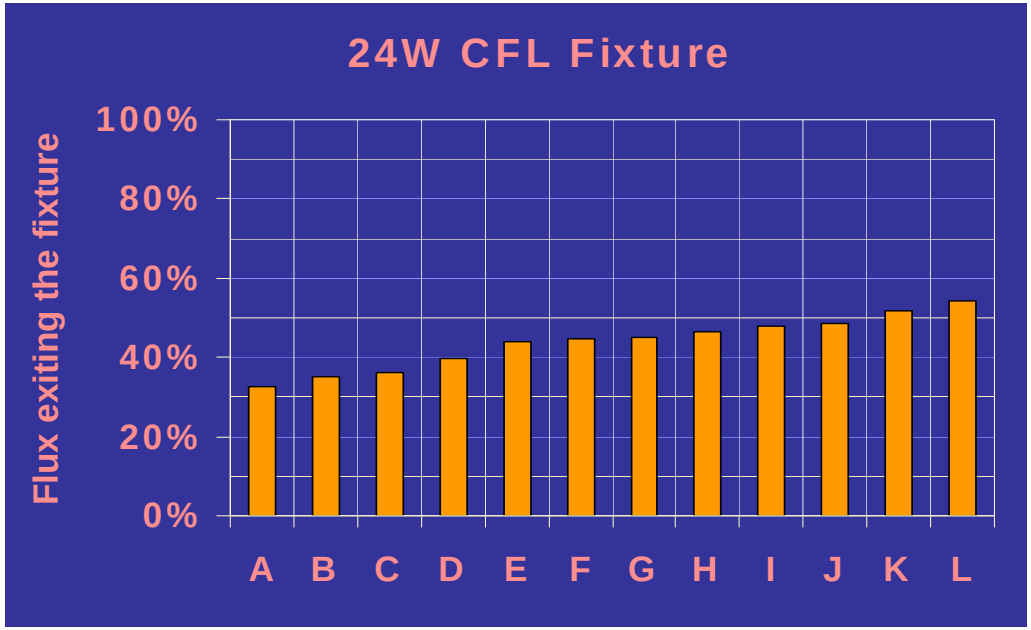




Luminaire efficacy

- In this example, the total luminaire efficiency is 33% to 54%.
- A 60 lm/W CFL would yield:
  - 19 to 32 lm/W final system efficacy in these luminaires
  - IR Halogen PAR lamp would be a better choice than combinations A to J

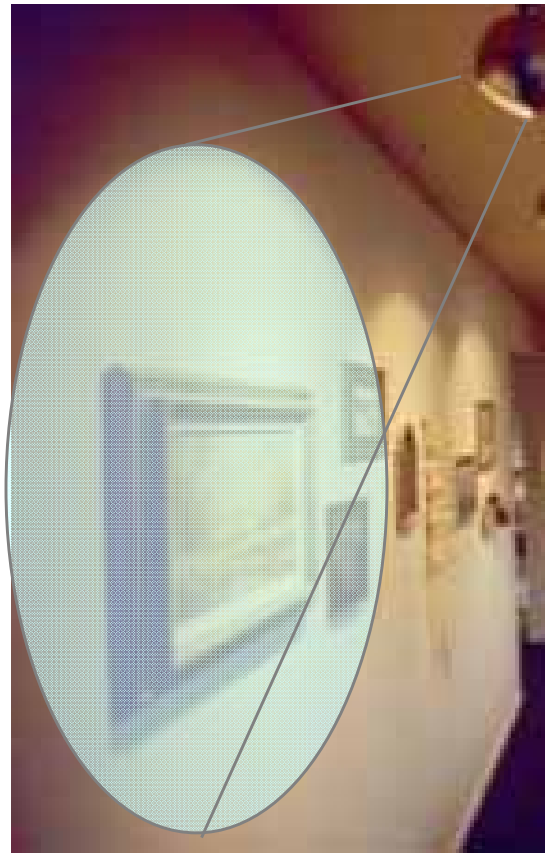


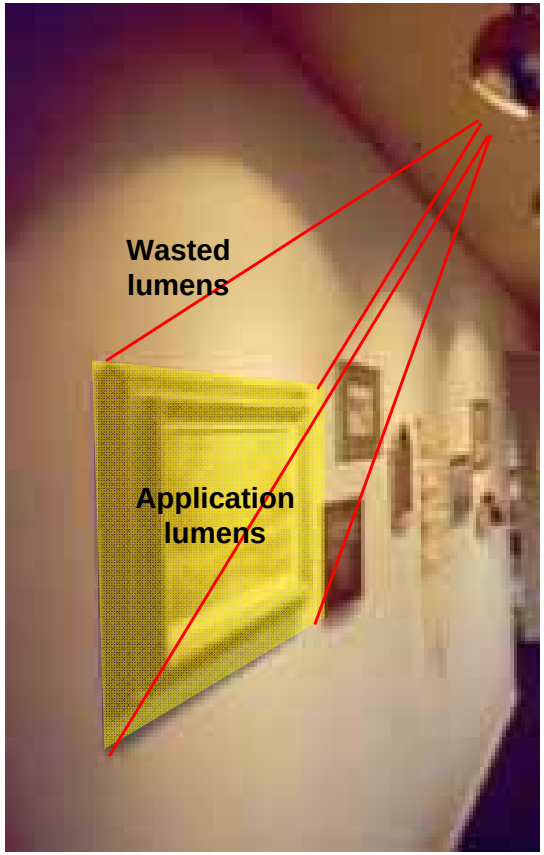


Application efficacy

Lighting Objective – Illuminating the picture on the wall

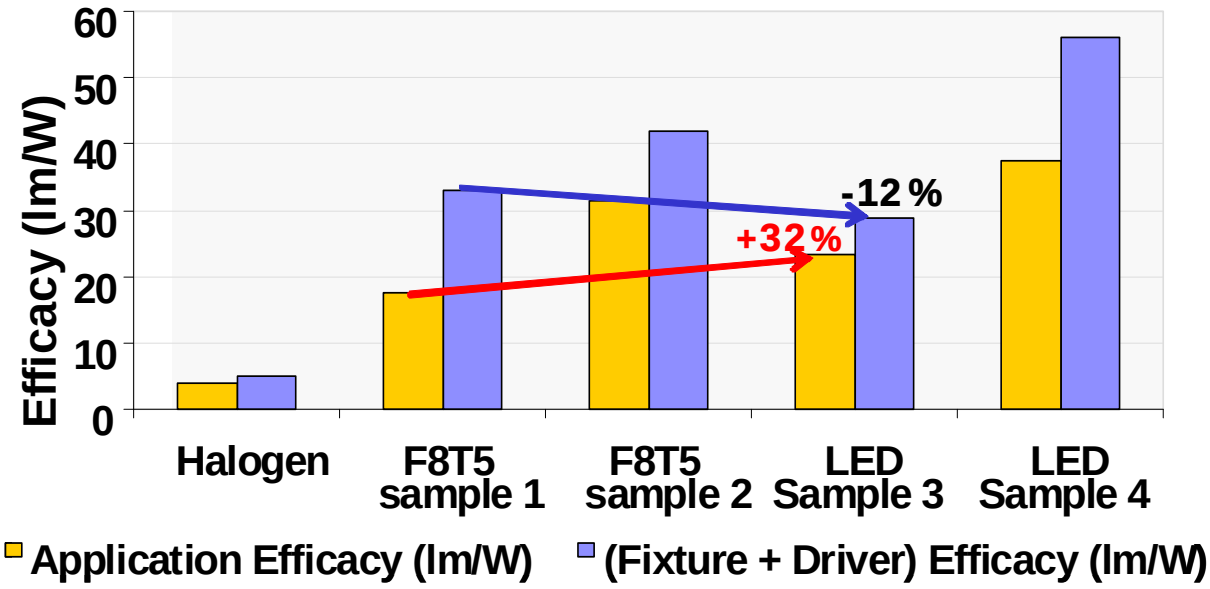
- **Application lumens:** Total lumens reaching a picture area
- **Wasted lumens:** Lumens beyond the area of the picture





Application efficacy

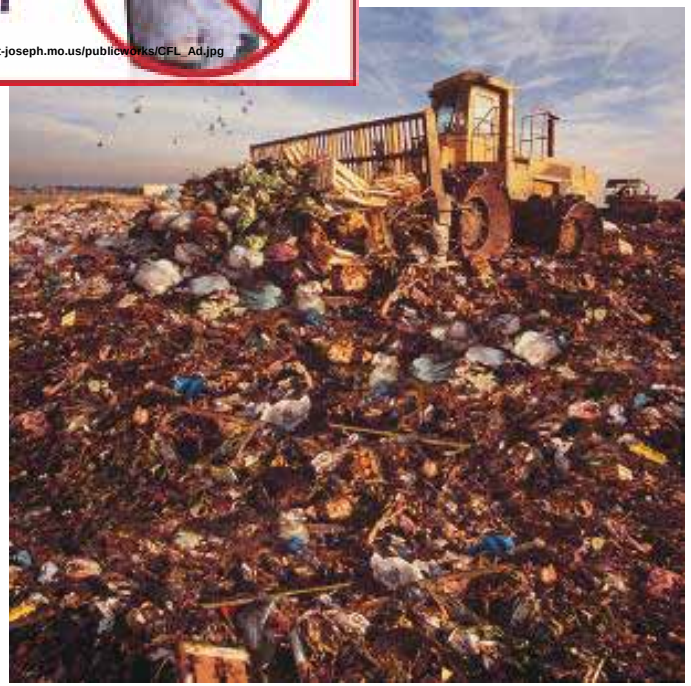
- In this example, compared to sample 1, sample 3 is designed better to direct the exiting lumens to the area where it is needed.



Environmental considerations

- Mercury
  - Mercury is an essential component of many energy-efficient light bulbs.
  - Throwing these lamps into the garbage bins, which ultimately end up in landfills, can pollute the environment.
    - ✓ Mercury in the environment can change to methylmercury, a highly toxic form that builds up in fish and shellfish.
    - ✓ Fish and shellfish are the main sources of methylmercury exposure to humans.
      - http://www.epa.gov/mercury/about.htm
- Health Effects
  - Mercury exposure at high levels can harm the brain, heart, kidneys, lungs, and immune system of people of all ages.
    - http://www.epa.gov/mercury/about.htm
- Lamp Disposal
  - Programs that promote energy-efficient technologies must also consider proper disposal programs for waste to minimize negative effects to the environment and people.

www.ci.st-joseph.mo.us/publicworks/CFL_Ad.jpg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Selecting Technologies for Energy-efficient Lighting Application

Lamps for residential applications

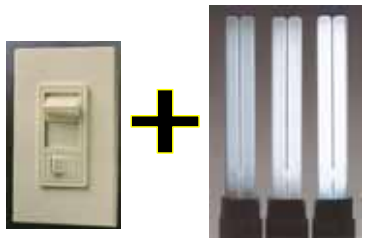
- Today, linear and compact fluorescent lamps can be used in houses to conserve energy and reduce nighttime power demand.

New fluorescent lamps provide incandescent-like warmth.

Lamps for residential applications

Lamps for commercial applications

- Today, linear and compact fluorescent lamps can be used in offices, shops, and hotels to conserve energy and reduce power demand.
  - Cool-white and warm-white options
  - Can use controls (occupancy and daylight) to save additional energy
  - Dimming is an option



Lamps for commercial applications

- Incandescent / halogen PAR and MR lamps are the most commonly used lamps in shops and hotels
- CFL and ceramic metal halide (MH) reflector lamps are beginning to serve these applications to reduce energy, especially in accent lighting applications.
  - Cool-white and warm-white options with improved color rendering properties
  - Lamp wattage: 39-150 W
  - Efficacy: 90 lm/W
  - Color rendering index: >80
- However, dimming CFL and MH could be difficult

GE Lighting

Philips Lighting

GE Lighting

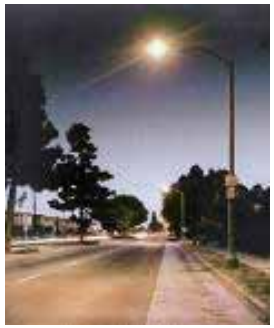
GE Lighting

Lamps for industrial applications

- Linear and high-wattage compact fluorescent lamps, and HID lamps can be used in industrial lighting applications.
  - High efficacy
  - 70-95 lm/W
  - Color rendering index >80
  - Can use controls (occupancy and daylight) to save additional energy

Lamps for roadway applications

- Today, HPS, HID, CFL, and LFL lamps can be used in roadway applications to save energy and reduce power demand.
- During nighttime conditions (mesopic vision), we are more sensitive to light of a higher color temperature.
- Several studies have demonstrated the benefits of mesopic street lighting
  - Observers' perceptions of visibility, safety, brightness and color rendering are more positive with mesopically tuned lighting.
  - A 30% reduction in power is possible while maintaining visual performance.



HPS
2100 K

CFL, LFL, MH, or LED
>4000 K

Rapidly emerging light sources

- Now, solid-state light (SSL) sources—LEDs and OLEDs—are evolving to displace some of the traditional light sources in some applications.

Light-Emitting Diode (LED)

LumiLeds

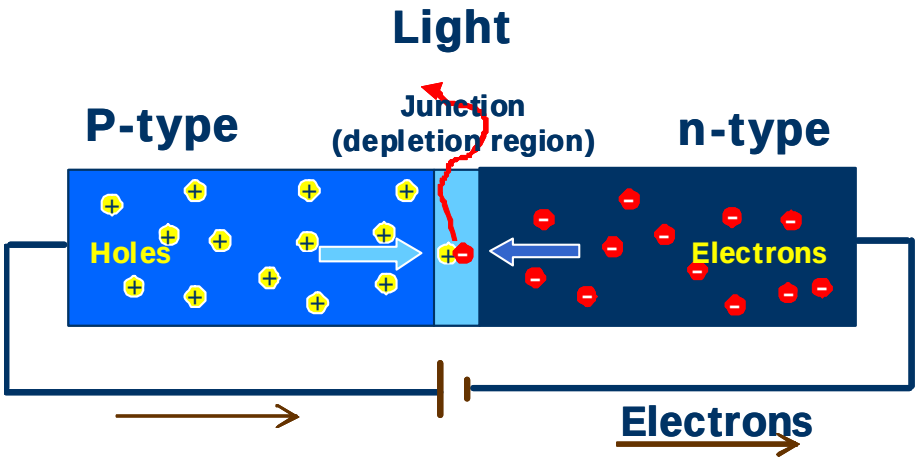
OSRAM Opto

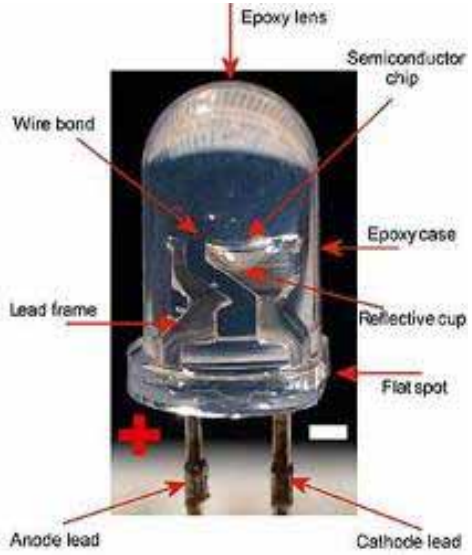
Cree

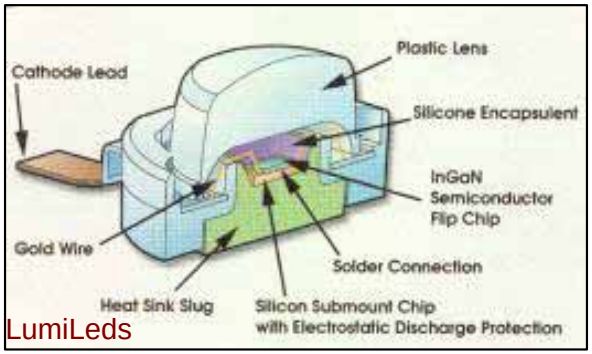
Light-Emitting Polymer (LEP)
Organic Light Emitting Diode (OLED)

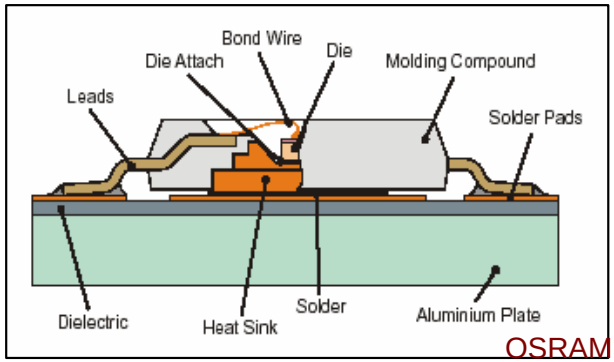
What is an LED?

- Semiconductor p-n junction



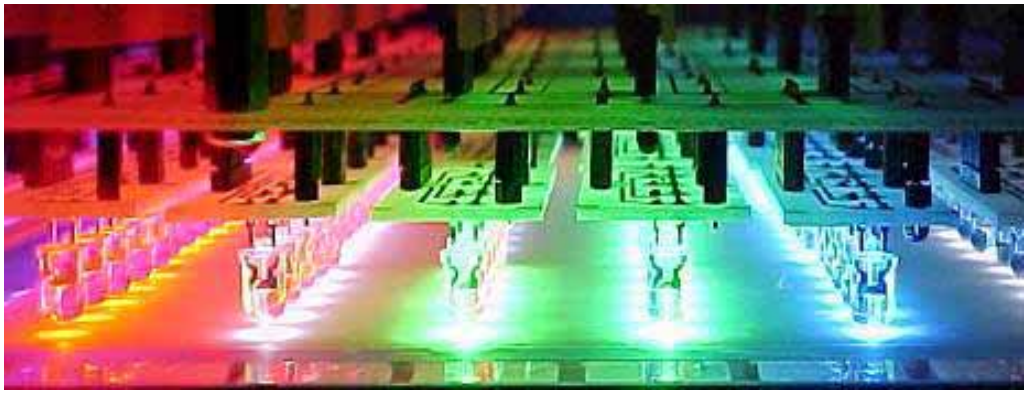


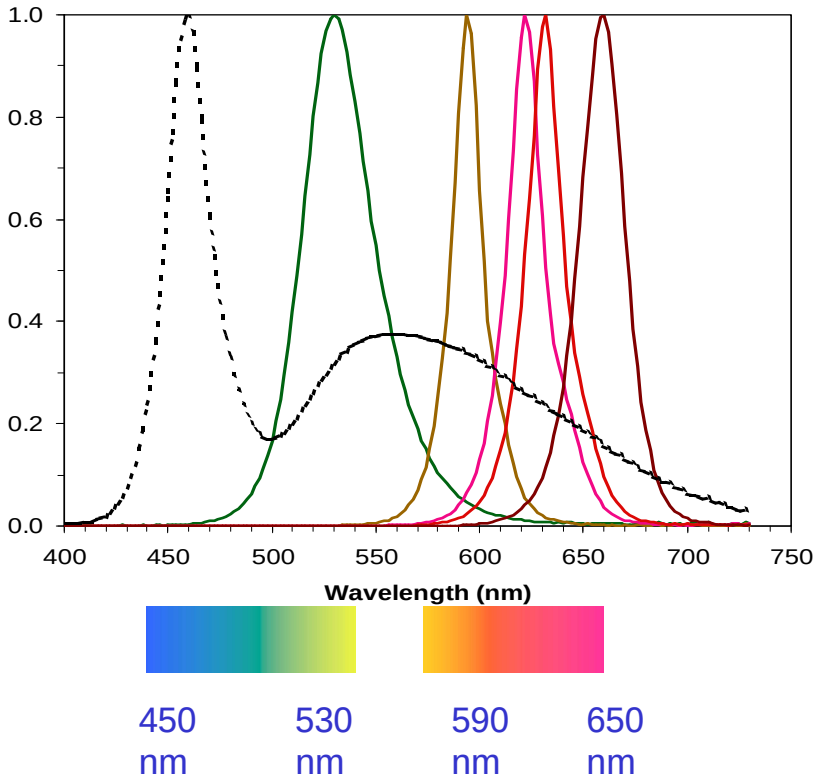


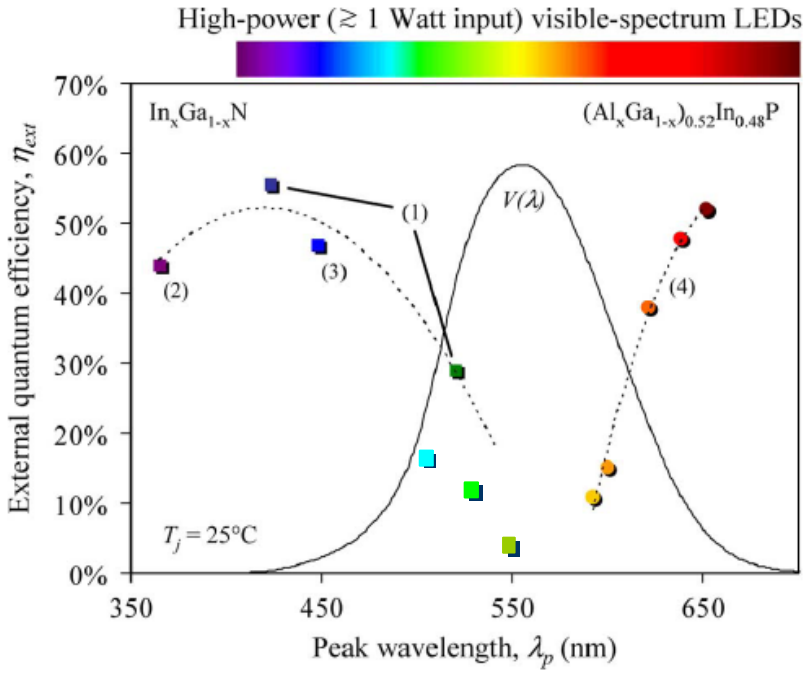


Colored LEDs

- All colors within the visible range.
  - However, efficiency is not equal at all wavelengths.

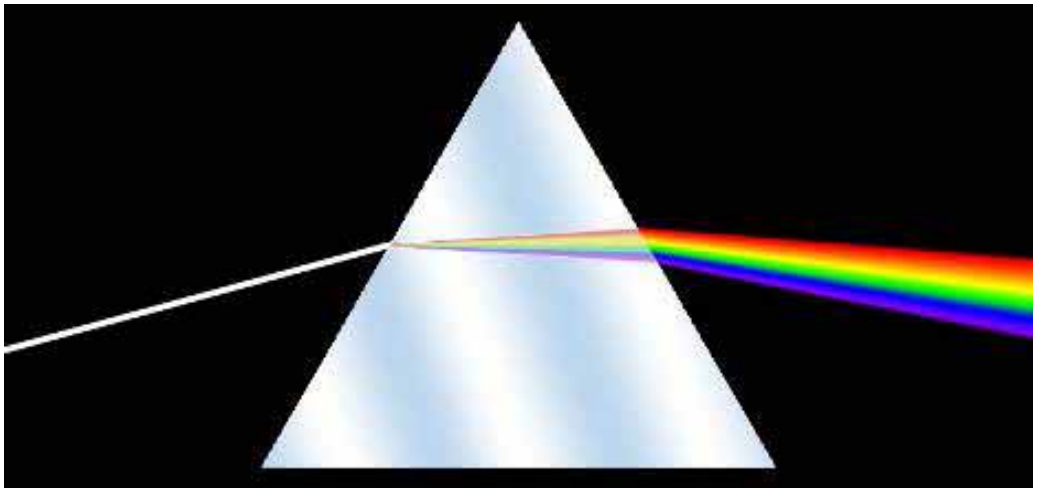






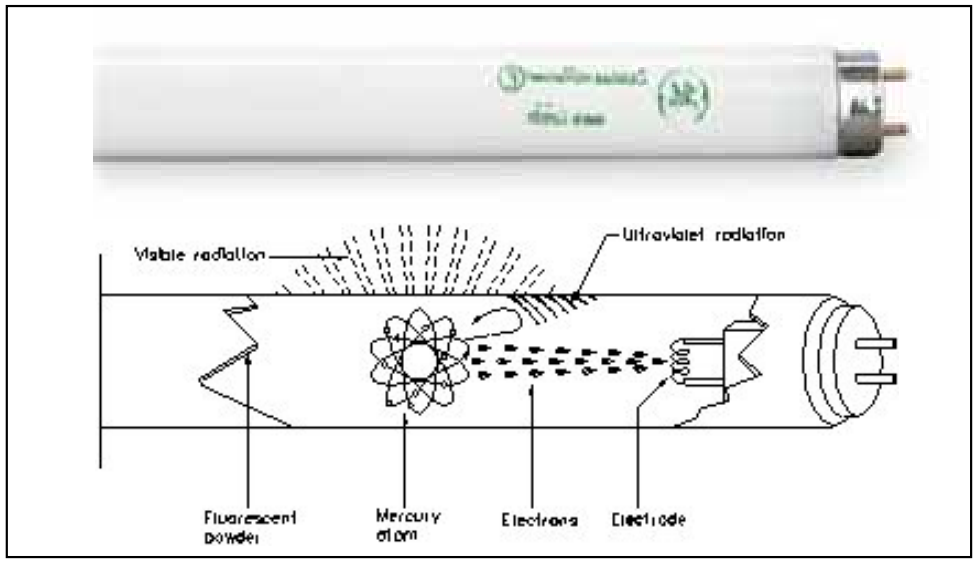
Creating white light with LEDs

- Mixing different colored LEDs (red, green, and blue) in the right proportions produces white light.
  - RGB – LED Systems



Creating white light with LEDs

- Combining blue or UV LEDs with phosphors produces white light.
  - Phosphor-converted White (PC-white)



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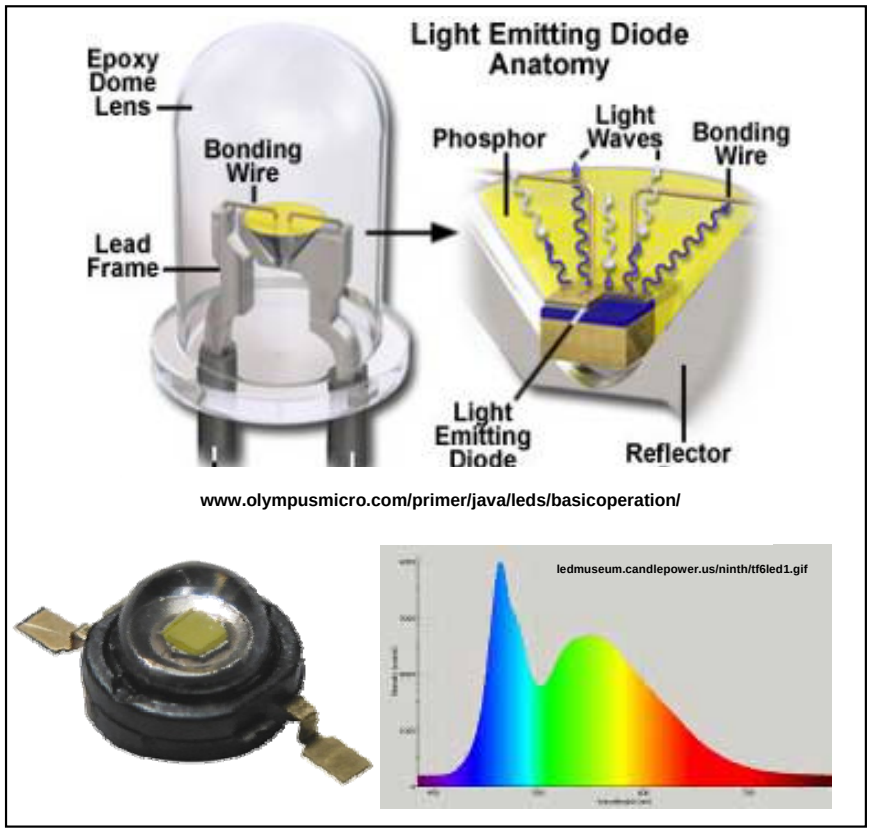
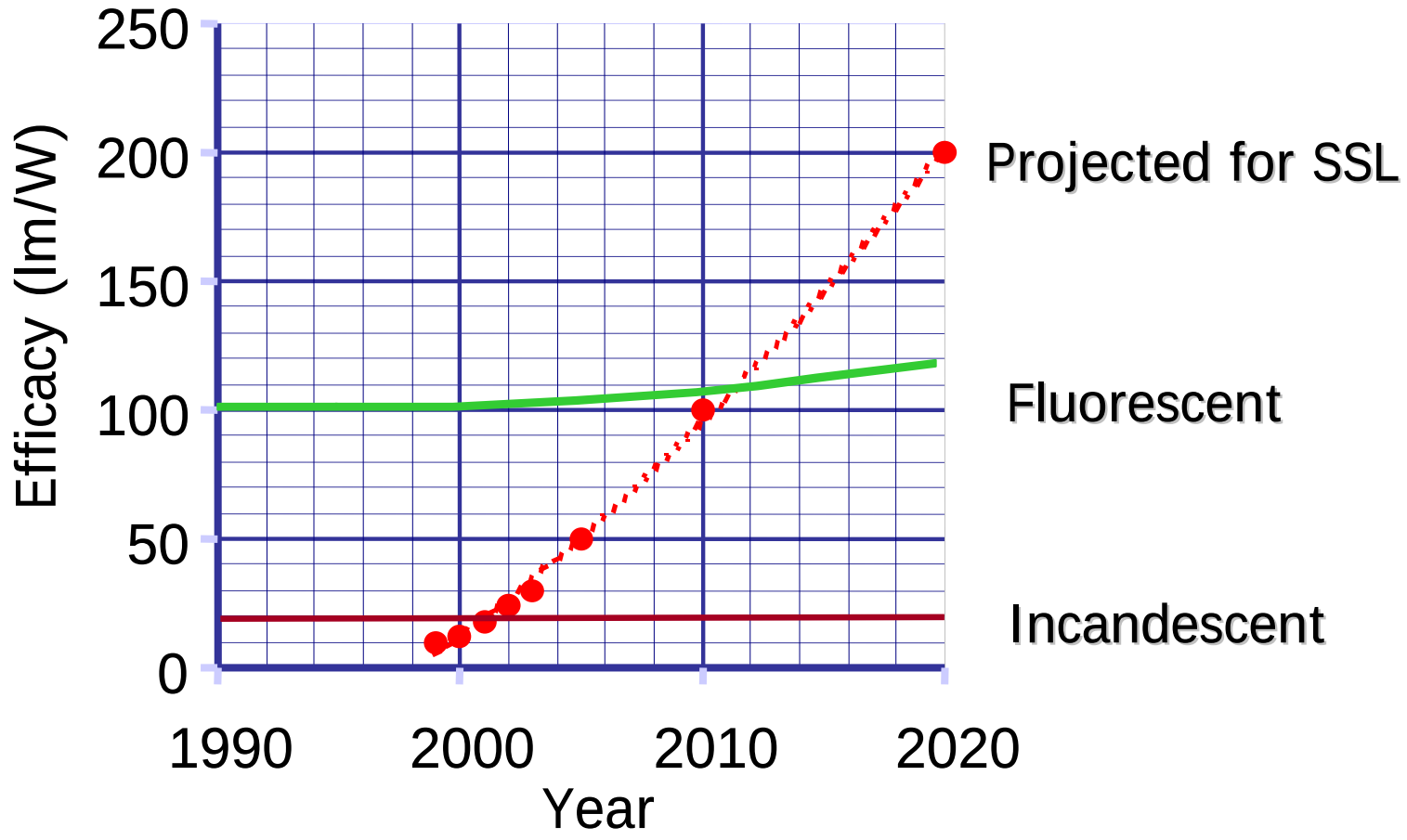


Projected efficacy

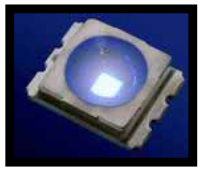
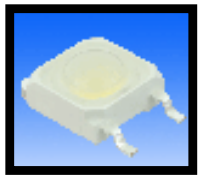
- SSL sources hold the promise to reduce electric energy use by 50%

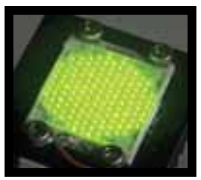


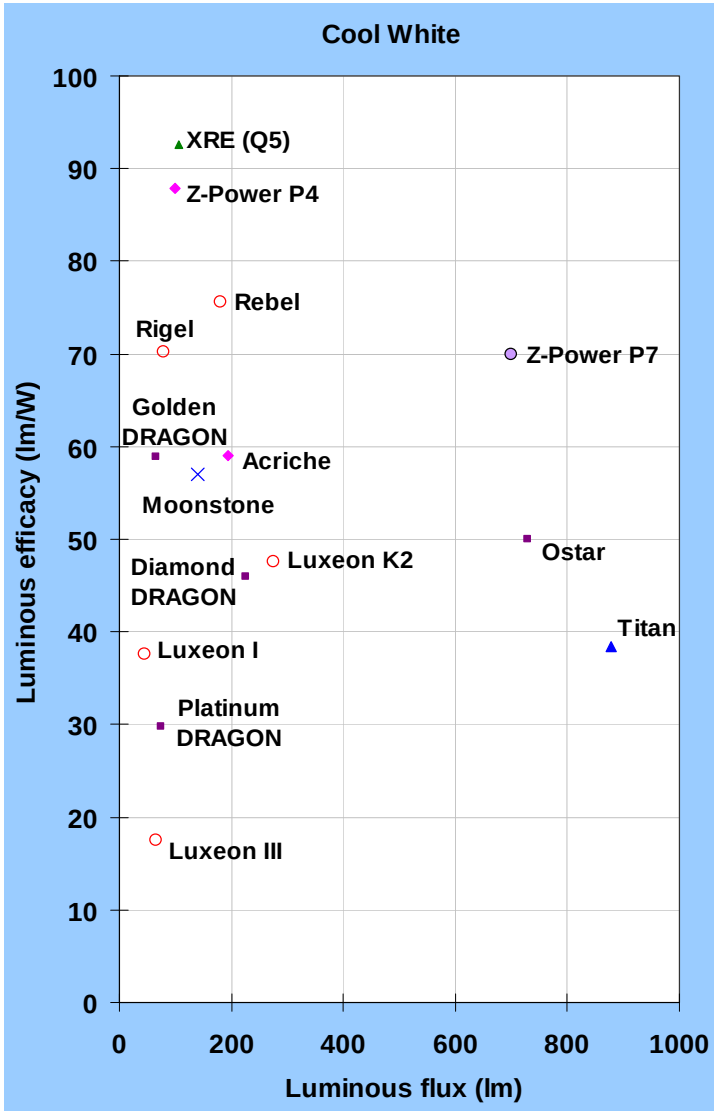
National programs around the world

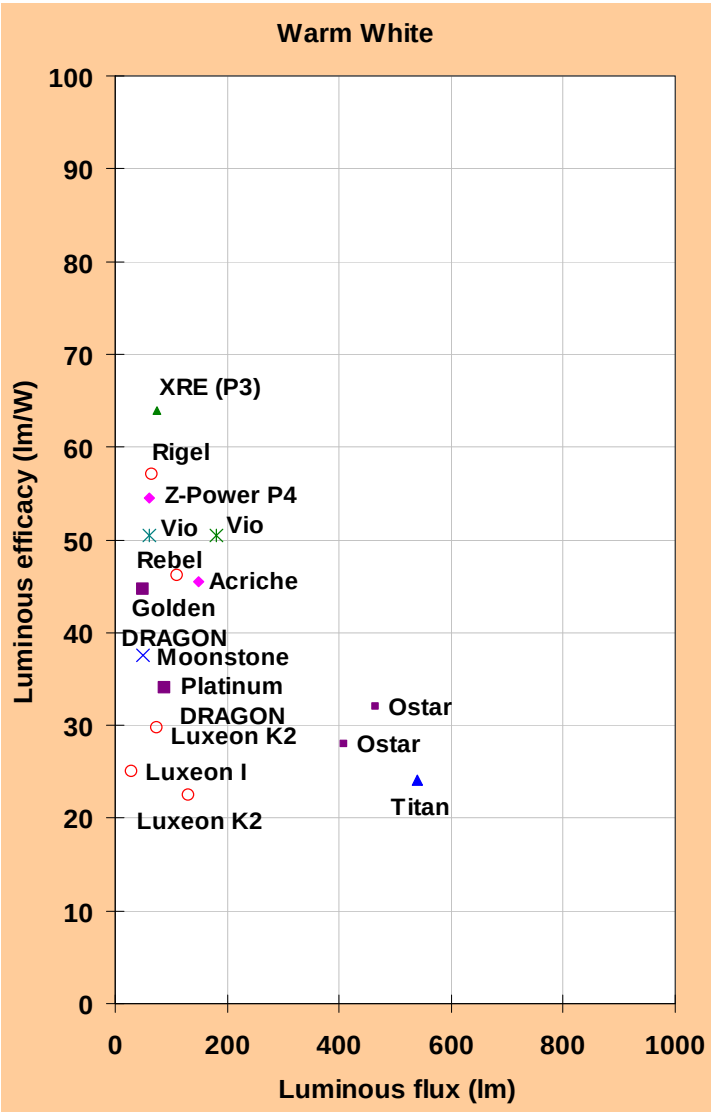
- In 1998, Japan initiated the first national program to catalyze SSL technology.
  - The Japan Research and Development Center of Metals established the five-year national project "Light for the 21st Century".
- In early 2000, USA initiated a national program in SSL.
  - Congressional Appropriation for SSL Portfolio, 2003-2009
    - ✓ US DOE Program Mission: Guided by a Government-industry partnership, the mission is to create a new, U.S.-led market for high-efficiency, general illumination products through the advancement of semiconductor technologies, to save energy, reduce costs and enhance the quality of the lighted environment.
- In mid 2000, China started their national program in SSL.
  - $350M RMB($70M USD) was invested from the Ministry of Science and Technology to support the development of solid-state lighting. The five-year program is lead by Ms. Wu Ling.
- Several other countries have initiated national SSL programs to catalyze energy efficiency in lighting.

Commercial white LEDs





LED applications

Mid-2000

Early 2000 to mid-2000

Late 1990s to early 2000

Festival lighting

- Power demand increases during festivals where lights are used
  - Colored lights
- LEDs can reduce load and save energy

Present trends

Outdoor Street and Area Lighting

www.treehugger.com/files/2008/07/led-streetlights-anchorage-alaska-16000.php

LED streetlights to take over downtown Ann Arbor

17 Oct. 2007 – Ann Arbor plans to become the first U.S. city to convert 100 percent of its downtown streetlights to LED technology, with the installation of more than 1,000 LED fixtures.

EcoWorldly

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Phillips Unveils Solar/Wind Hybrid Streetlights in Moscow

Written by Sam Aala Daka — Published on October 17th, 2008 in Global — 3 Com

OSRAM Opto Semiconductors today announced that its Golden DRAGON LEDs are lighting up a major thoroughfare of Jing Jiang City in the Jiangsu province of China. The 180W prototype LED streetlights were installed by Jiangsu Hua Jing Photoelectronics for replacing traditional 250W HID lamps.

GE Lumination's outdoor LED area light

According to the article, it saves up to 60 percent energy, longer life, and significantly improved light-level uniformity compared with traditional HID lamp sources and optical systems, such as a standard 400-watt quartz metal halide system

www.ledjournal.com/.../june/GE_outdoor%20LED.jpg

Present trends

Replacement Lamps & Light Engines

Figures from: Progress Lighting

Figures from Prescolite

Present trends

Downlighting

Cree and Zumtobel Announce Strategic Agreement for LED Downlights in Europe

Global Adoption of Solid-State Lighting Accelerating At a Rapid Pace

Last update: 2:00 a.m. EDT Oct. 8, 2008

Sharp Corporation will introduce into the Japanese market six new LED Downlight Lightings, including three that deliver a light intensity equivalent to a 150-watt incandescent lamp, an industry first for downlight models.

General illumination

From the Press:

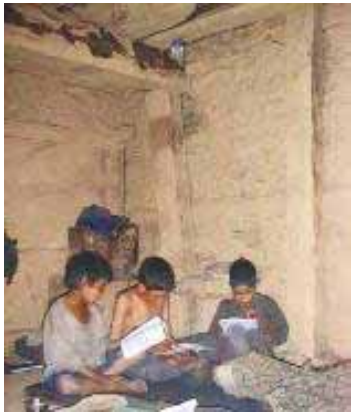
- Over 4,200 recessed LED lights to be installed in the Pentagon.
- Recessed LED lights to save over 22 percent energy compared with fluorescent lights, and save 140 tons of carbon dioxide emissions per year.

Before: A Pentagon room before Cree's LED lights were installed.
(Credit: Cree)

After: The same room at the Pentagon after Cree's LED lights were installed
(Credit: Cree)

Lighting rural homes

- Kerosene lamps are the predominant source for lighting in many rural homes
  - Expensive
  - Hazardous
  - Poor quality lighting



David Irvine-Halliday, founder of the Light Up The World Foundation (Calgary, Alberta, Canada)

- Affordable battery powered LED, LFL, or CFL lamps can be effective in providing lighting solutions to rural homes

Lighting transformation

LEDs are providing new life to old systems

www.stuga-cabana.com/petromax.gif

www.backcountry.com/store/CMN0105/Coleman-8D-...

www.wordjourney.com/images/kerosene-lamp.jpg

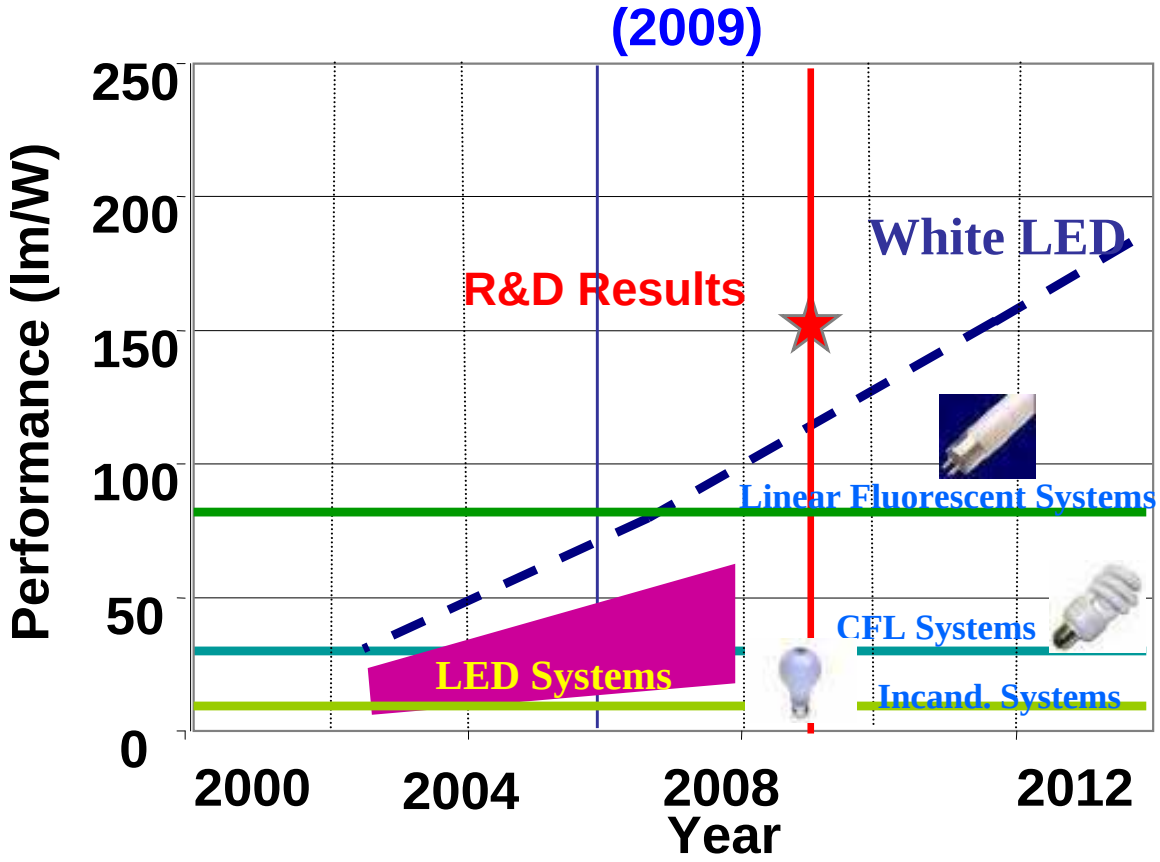
www.allproducts.com/.../torches/product5-s.jpg

www.giftsscentfromheaven.com.au/shop/images/l...

www.shoppingmallsonline.org/uploads/images/be

LED lighting systems performance

- To the end user, system performance matters …not source performance.
- At best, LEDs have 60% system efficiency.
  - Even though the best LEDs can have 100 lm/W, lighting systems will be at 60 lm/W.
  - Majority of commercial LED products have efficacies in the range of 10 to 30 lm/W.

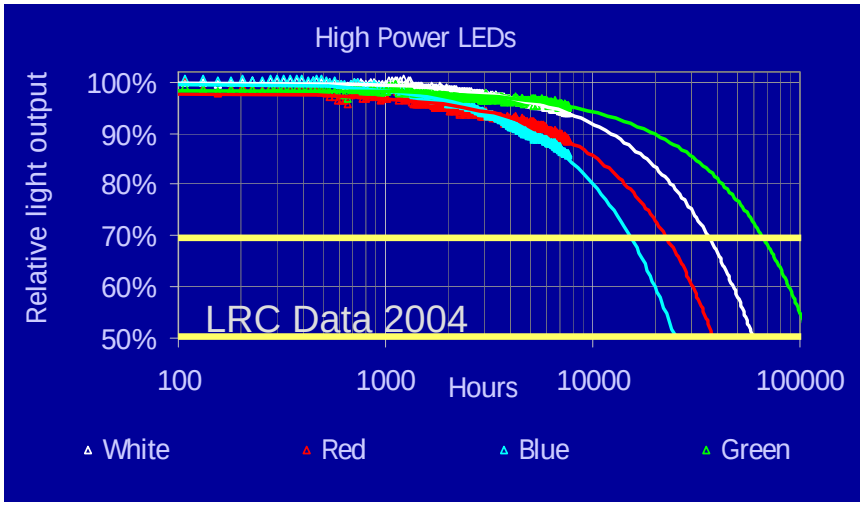


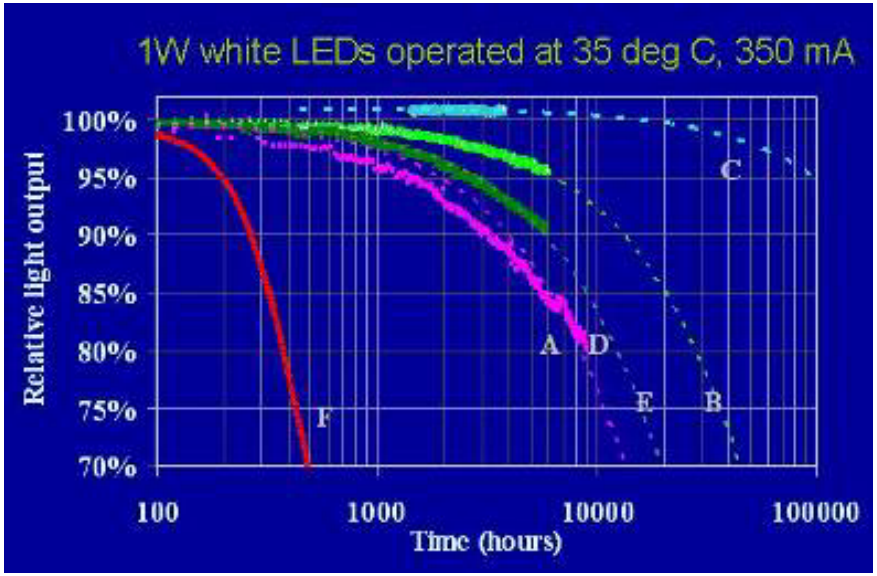

www.blogcdn.com/.../2007/02/led-light-bulb.jpg


www.global-b2b-network.com/.../LED_Light.jpg

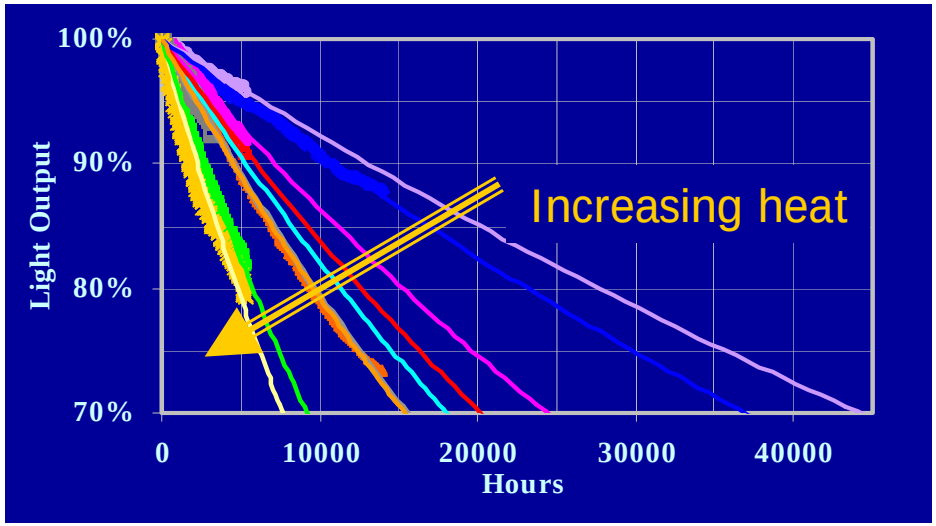

deals2give.com/.../uploads/2007/07/p13112a.jpg

Reliability is still a concern





Buyer beware…



Over-promised products

Long life is not a guarantee. System integration greatly determines the life of the product.

Final thoughts

- Selecting a product for an application can be challenging.
  - Quality varies significantly
- Look for independent laboratory test reports.

http://www.lrc.rpi.edu/programs/NLPIP/about.asp

www.ci.berkeley.ca.us/.../lightbulbs2.jpg

www.nesllc.com/images/Compact-Array.gif

Thank you

40W

Incandescent

10W

CFL

7W

LED

Technology on the move