# *A View on The Future of Solid State Lighting*

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# Outline

- LED as a light source
- Major challenges
- LED applications
- LED Performance Targets

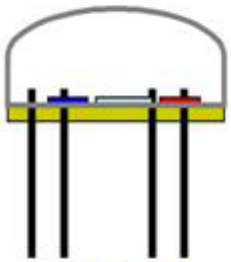
# Types of LEDs

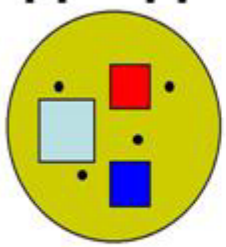
| Composition | Color |
|---|---|
| Al In Ga P | red, amber, yellow |
| In Ga N | green, blue |
| In Ga N + Phosphor | white |

# White Light Generation with LEDs

A. Multi-chip LED

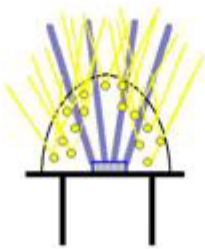
**RGB - IDEAL**





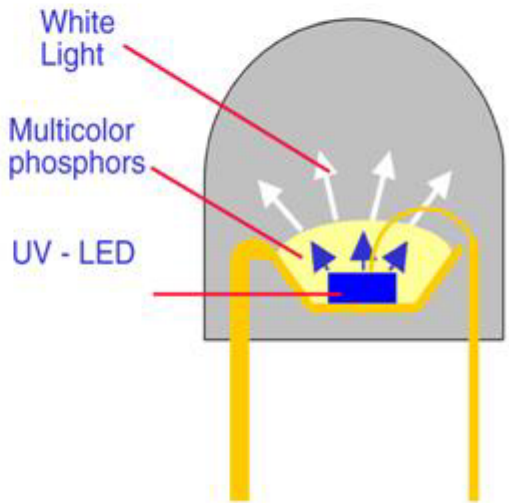
**NOT AVAILABLE**

B. Blue LED + Phosphor(s)



**Low Stability, CRI, and Cost**

C. UV LED + Phosphors




**Moderate Stability, CRI, and Cost**

# Light Source Comparison

| Attributes | LED now | Incandescent | CFL |
|---|---|---|---|
| CRI | 40-80 | 100 | >80 |
| Watts/lamp | 1 | 100 | 23 |
| lm/lamp | 30 | 1600 | 1600 |
| lm/Watt | 20 - 30 | 16 | 60-80 |
| $/klm | 130 | .6 | 5 |
| Life (Hrs) | 5,000* | 750 | 8,000 |

***End of life definition is missing**

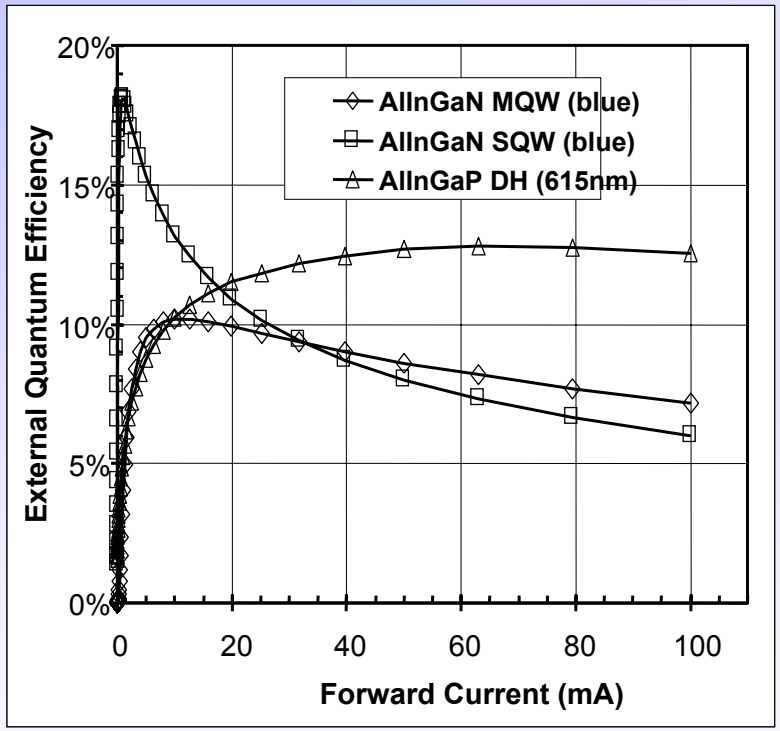
# Infrastructure Comparison

| PARAMETER | LED | INCANDESCENT |
|---|---|---|
| Voltage | 2.8 - 4.5 V | 110 V |
| Current | DC | AC |
| Temperature Compensation | required* | not required |
| Heat dissipation | conduction | radiation |
| Light output | directional | Over 360 $^{o}$ |

***Luminous flux decreases with increasing ambient temperature**

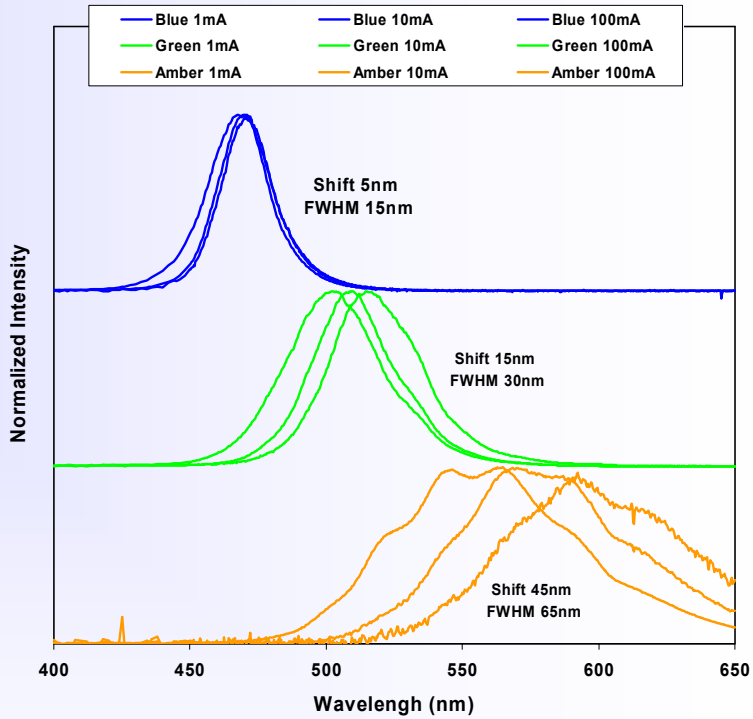
# Efficiency and Color Change vs. Current Density

## Efficiency




**AlInGaN LED quantum efficiency drops with increasing current, whereas AlInGaP is constant to high drive currents.**

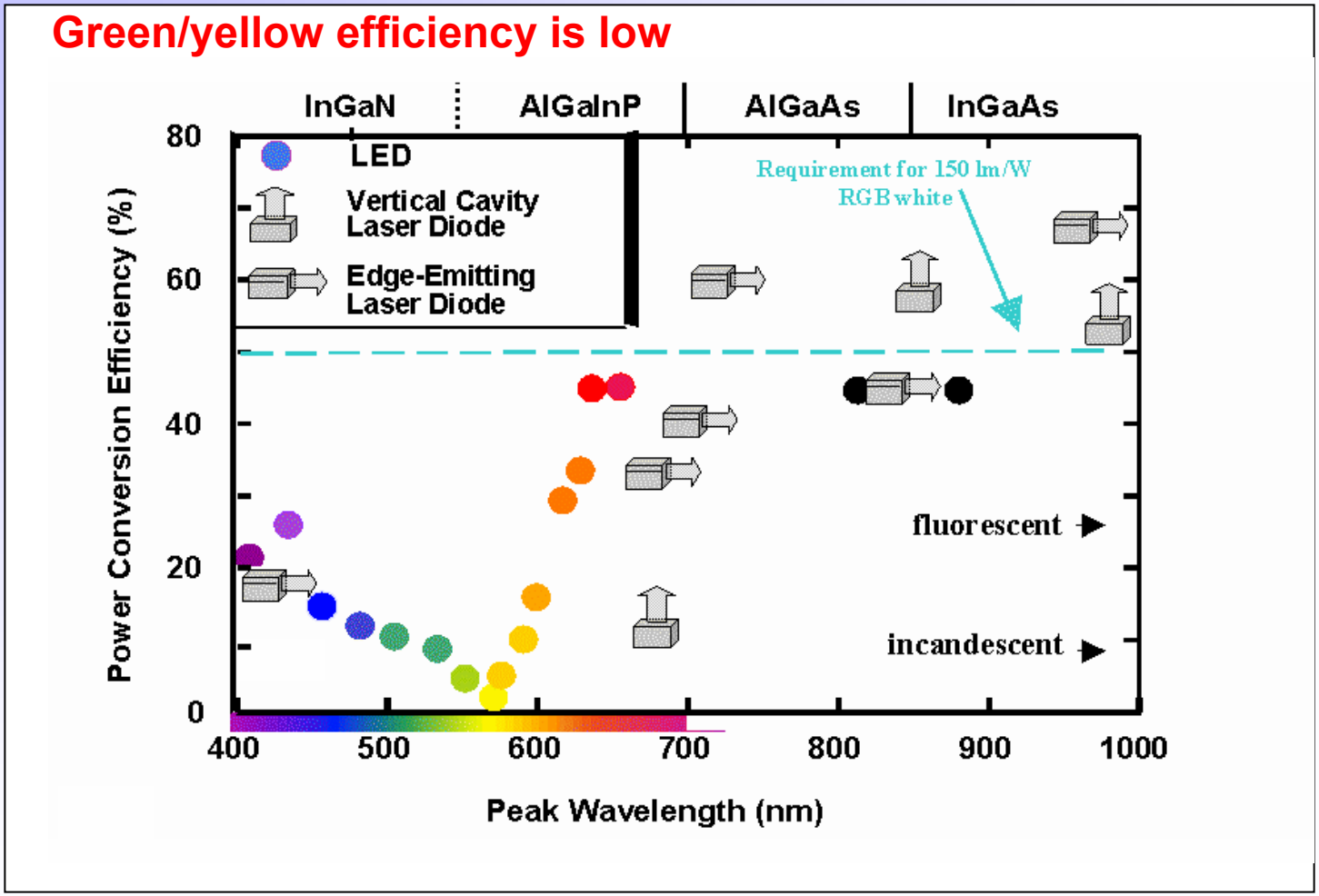
## Color Change




*Shift to shorter wavelength with increasing current.*

Source: George Crawford, Robert Karlicek

# Power Conversion Efficiency vs. Wavelength for the Best Reported LEDs and Lasers




Source:
George Craford,
Lumileds

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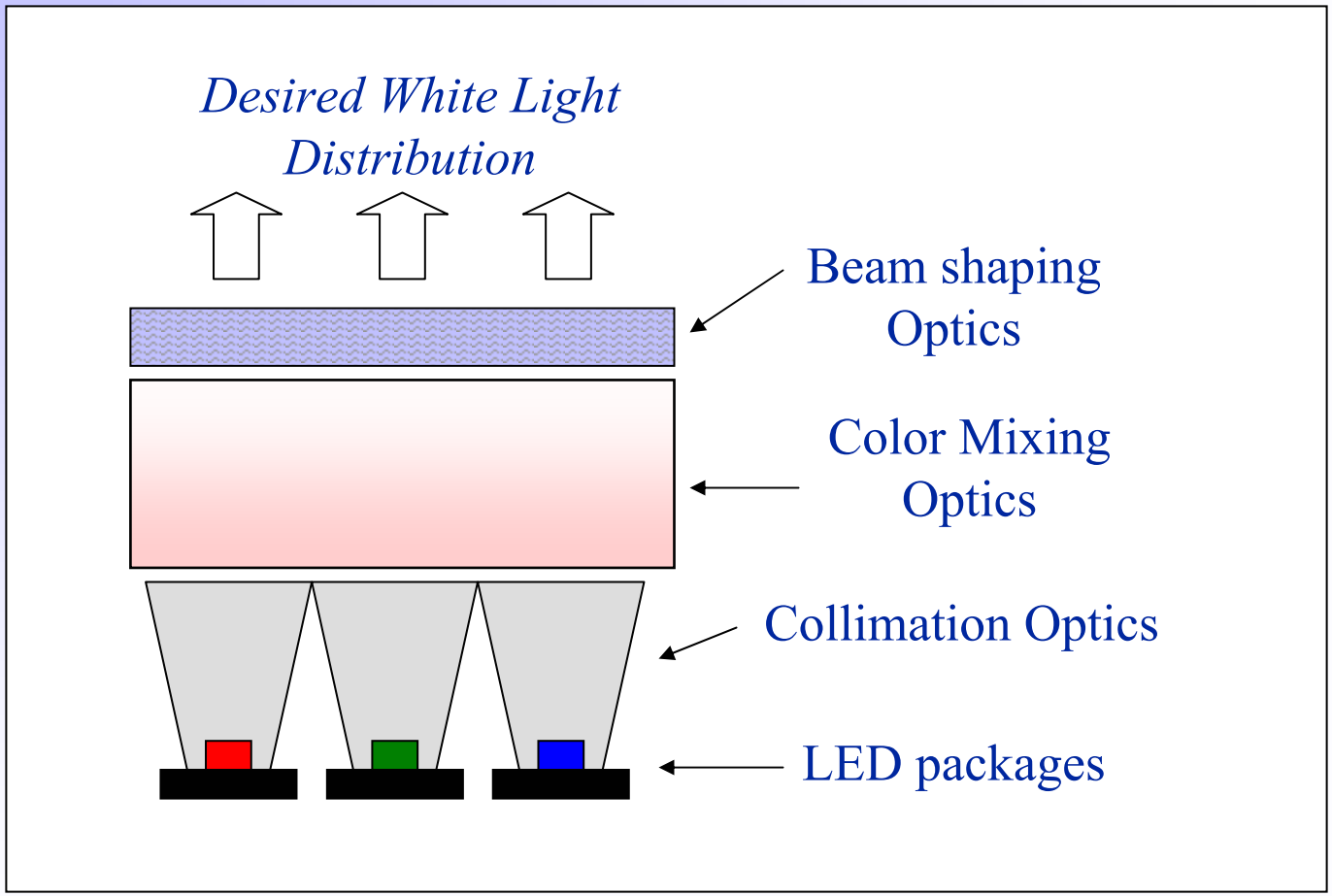
# Major Challenges

1. Develop low cost, variable color RGB LED lamps - requires breakthrough
2. Achive 120 lm/W LEDs - green efficiency and extraction efficiency require breakthroughs
3. Compact fluorescent lights (CFL) will probably replace incandescent lights. Low cost LEDs might later replace all fluorescent lamps
4. Fit LEDs into Edisonian sockets. LEDs need different infrastructure and heat management

# RGB LED Optical Architecture

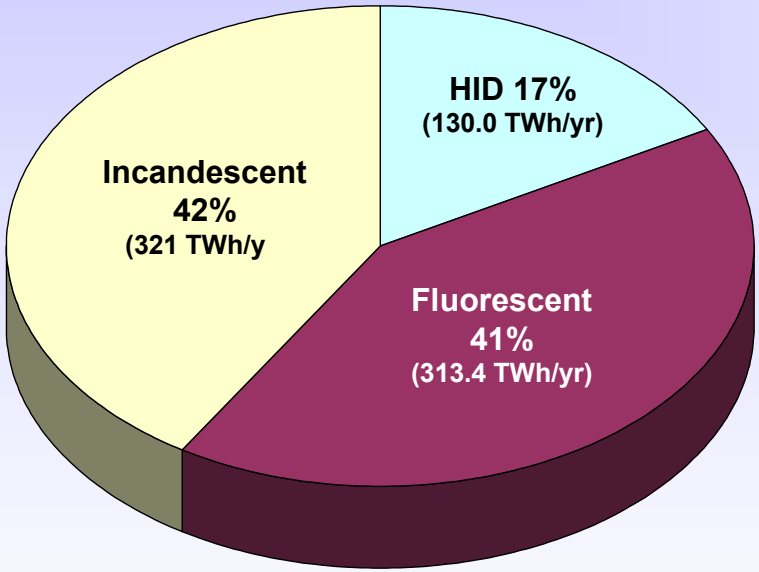


# Barriers to RGB LED Lights

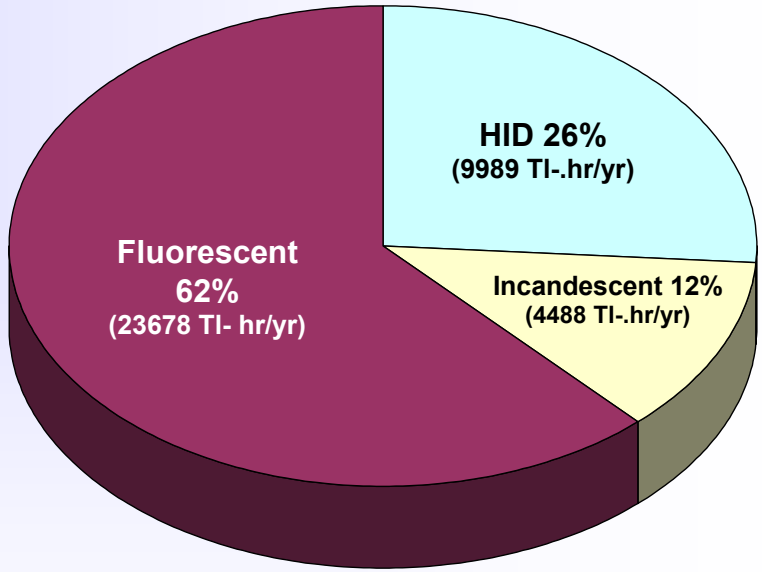
- Lack of high efficiency at all colors (especially in the yellow/green where luminosity is the highest)
- Low, typically 20%, light extraction efficiency (from high refractive index semiconductor to low refractive index air)
- Lack of efficient color mixing
- Need to dissipate heat by conduction (incandescent lamps dissipate heat by radiation)

# How to Save Energy for Lighting?

## National Energy Use (2000)




## Total Light Output (2000)

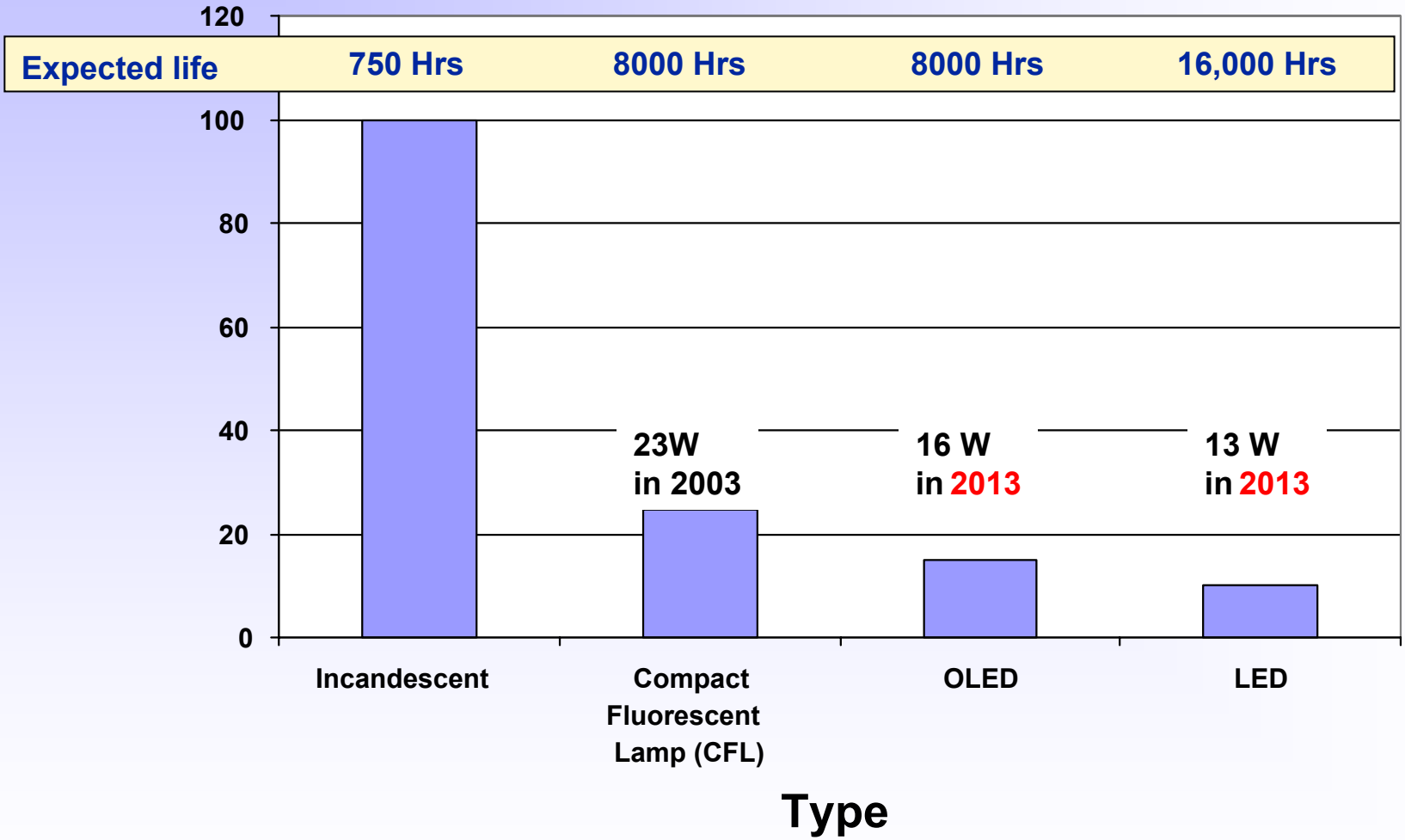



**Greatest Opportunity: Replace incandescent Lamps**

Source: DOE 2002 Buildings Energy Databook,
BTS/Navigant Consulting, U.S. Lighting Market Characterization Phase 1 National Lighting Inventory and Energy Consumption Estimate, July 2002

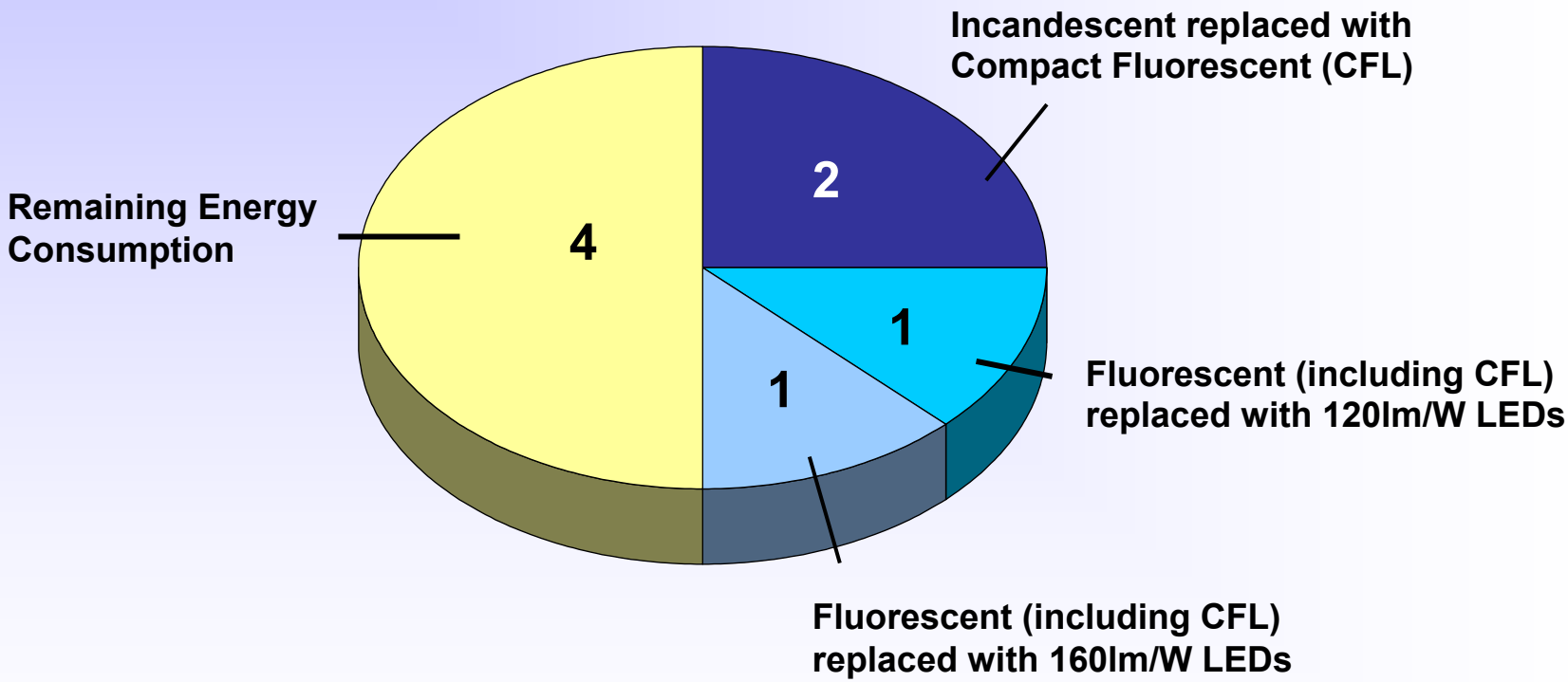
# Power in Watts Required to Generate 1600 Lumens

*(Light output comparable to a 100 W conventional incandescent light bulb)*



# Potential Energy Savings

## Potential Energy Savings for Lighting (Quads)



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# LED Applications

- **Current applications:**
  - Monochrome signaling (traffic lights, automobile tail lights, exit signs, etc)
  - Portable appliances (cell phones, PDAs, etc.)
  - Signage (replace neon signs, etc.)
  - Direct view large area displays (Time Square, Stadiums)
- **Emerging applications**:
  - Mobile platforms - signaling and lighting (automobile, aviation, marine lighting, trains, etc.)
  - Niche lighting applications (accent lighting, landscape/path lights, low wattage illumination: shelves, stairs)
- **Future applications (10-20 years from now):**
  - General illumination (residential, commercial)

# LEDs for Mobile Platforms

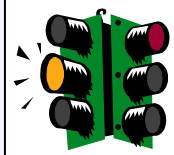
- Good match of attributes and requirements
  - Rugged, shock resistant
  - Low power consumption
  - Small size
  - Long life
  - Interchangeable for lighting and signaling
- Compatible powering:
  - Low voltage, DC
- Platforms have short life cycle: 2-20 year replacement (buildings have 30-60 year replacement)
- Design flexibility
  - Many different sockets
  - Many power supplies

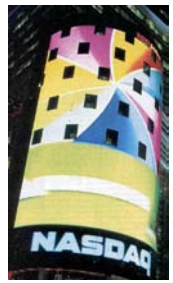
# LED Applications

**Now: monochrome**

Signage


Tail light


Traffic light



Large display

**Emerging: Mobile platforms**

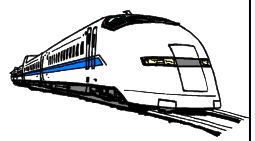

Ship


PDA


Car


Tank


Cell phone


Train

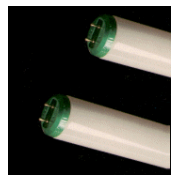

Airplane


Soldier

**Future: General Illumination**

**Replace:**


Incandescent


Fluorescent


CFLs

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# NGL Program Objectives

## *Assumed 10y - $500M Government Funding*

| Year | 2002 | 2007 (replace incandescent lamps) | 2012 (replace flourescent lamps) | 2020 |
|---|---|---|---|---|
| Performance (lm/W) | 25 | 50 | 150 | 200 |
| Lifetime (Hrs) | >1,000 | 10,000 | >10,000 | >10,000 |
| Color Rendering Index(CRI) | 60 | 80 | >80 | >80 |
| Light Output (lumens/lamp) | 20 | 200 | 1000 | 1500 |
| Cost Target ($/klm) | 500 | 50 | <15 | <3 |

# *Realistic SSL Targets?*

- Not available
- Must be established through a road-map process