LEDs

Yesterday, Today and Tomorrow

What can we expect in 2014?

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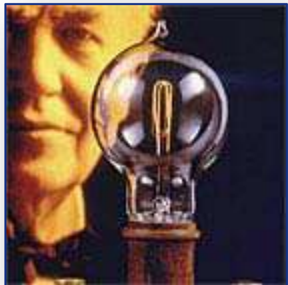
Mondays at Noon
Jan. 6, 2014
Sri Rahm, LC

What's so great about LEDs?

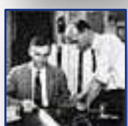
- Efficient light generation
- No wasted UV or infrared emitted
- Very long life
- Superior optics
- Various colors/color temperatures
- Easy to control: occ. sensors/dimming
- Work well in the cold
- No warm-up time



1987 - First Incandescent Lamp

GE Patents/Inventions

1934 – First HID Mercury Vapor Lamp



1938 - First Fluorescent Lamp

1959 – First Halogen Lamp

1961 – First HPS Lucalox Lamp

1962 - First Metal Halide Lamp

1962 - First Visible Light LED

All around 1960

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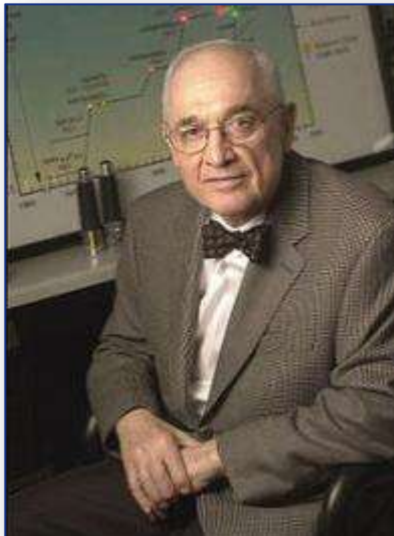
LED Founding Fathers



Nick Holonyak

Inventor of the first visible LED in 1962, while at the GE Research Center in Syracuse.

… predicted that his LEDs would replace the incandescent light bulb of Thomas Edison (in the February 1963 issue of Reader's Digest)

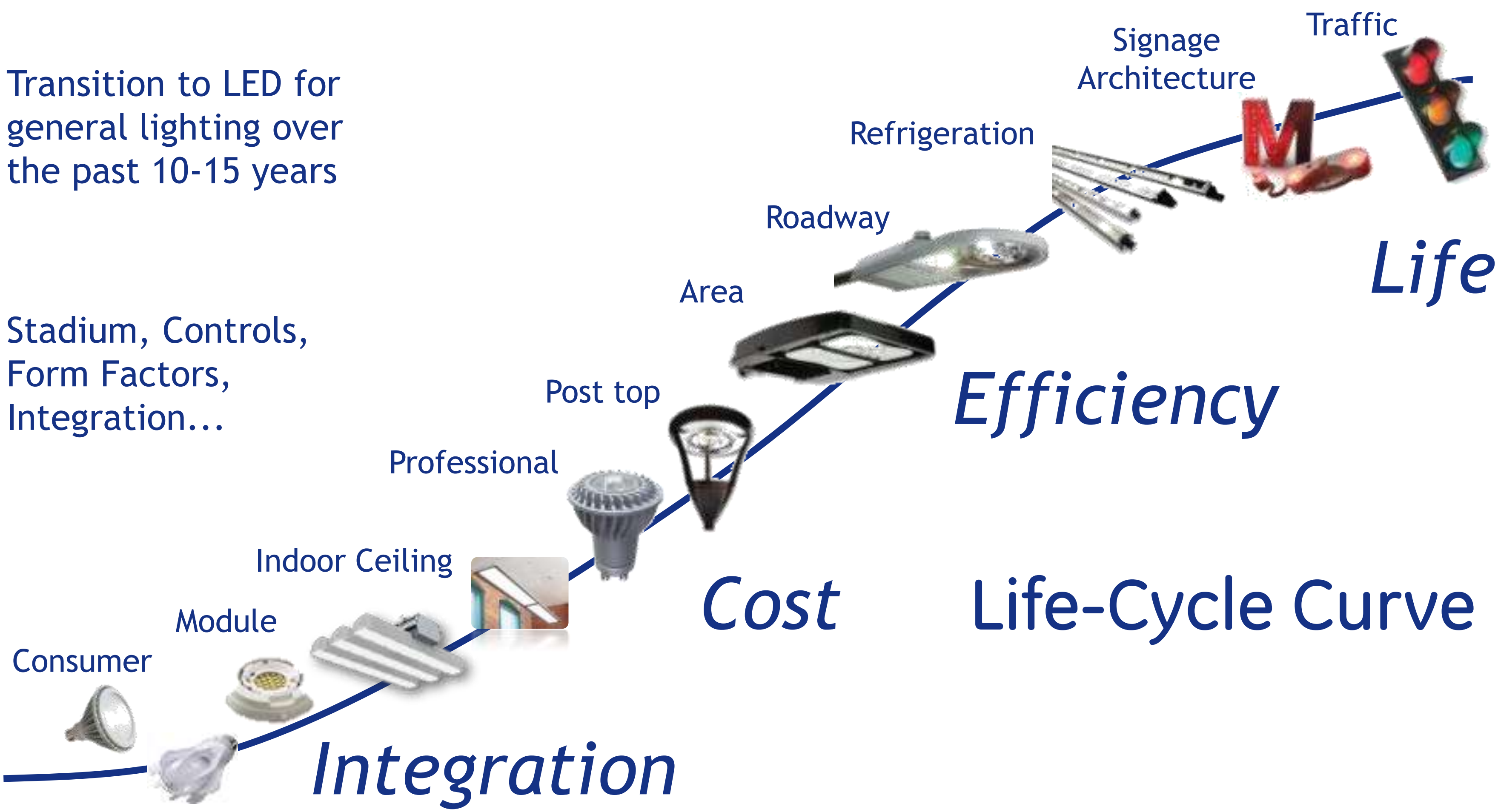
Shuji Nakamura

Inventor of the efficient blue LED in 1993,while at Nichia Laboratories in Japan

LED Applications – Activation Sequence

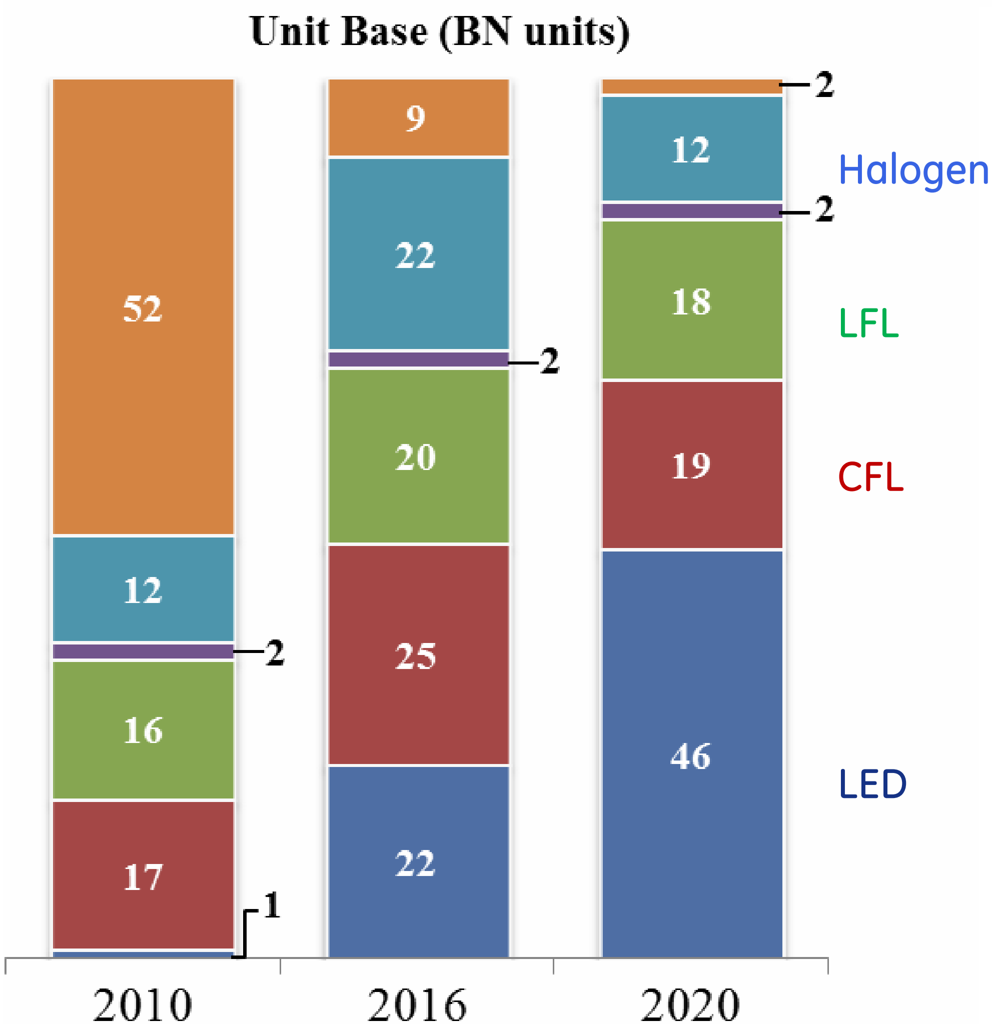
Transition to LED for general lighting over the past 10-15 years

Stadium, Controls, Form Factors, Integration...



Emerging | Growing | Mature

LEDs Tomorrow



McKinsey and Co.
"Lighting the Way" (2012)
Predictions for units sold

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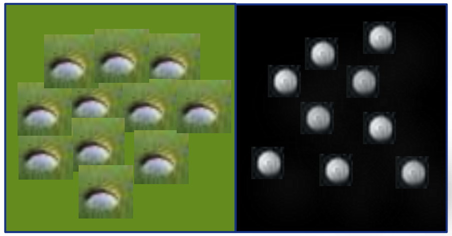
Structure of an LED-Light Emitting Diode

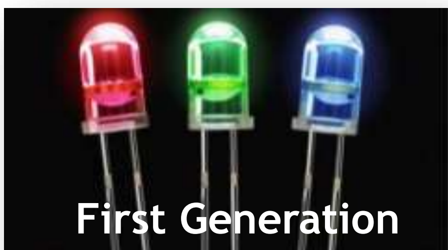
Semiconductor Material (solid)

P-material (holes)



N-material (electrons)

P-N Junction



Second Generation Surface-mounted

Most general lighting LEDs today are "blue" LEDs with a phosphor coated dome which emits other colors.

A "phosphor" is a material which absorbs blue or UV photons, re-emitting green, yellow, and red photons.

The color of the photon is a function of how deep the hole is:

Shallow hole:	red photon
Medium hole:	yellow photon
Slightly deeper hole:	green photon
Deep hole:	blue photon

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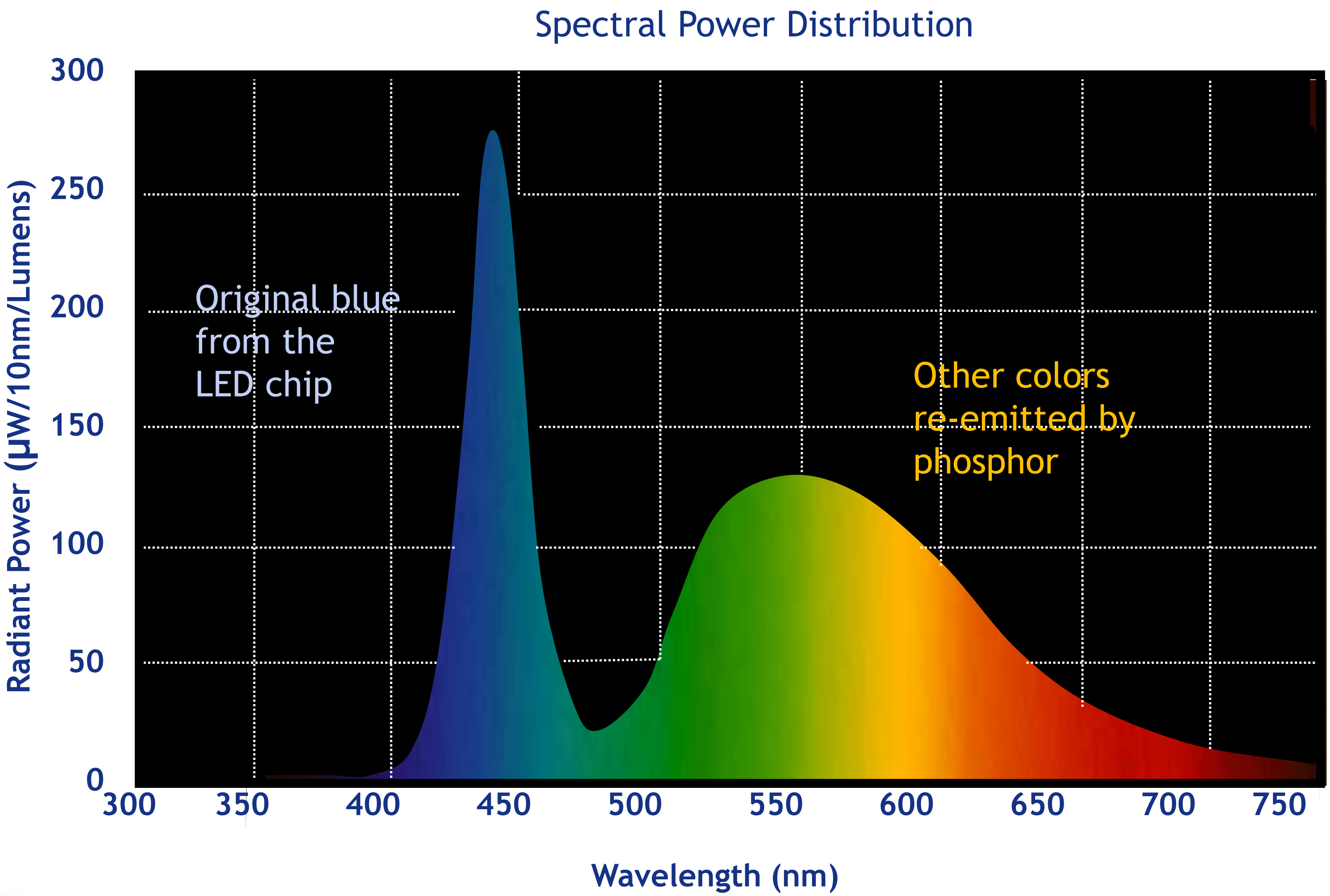
Typical White LED



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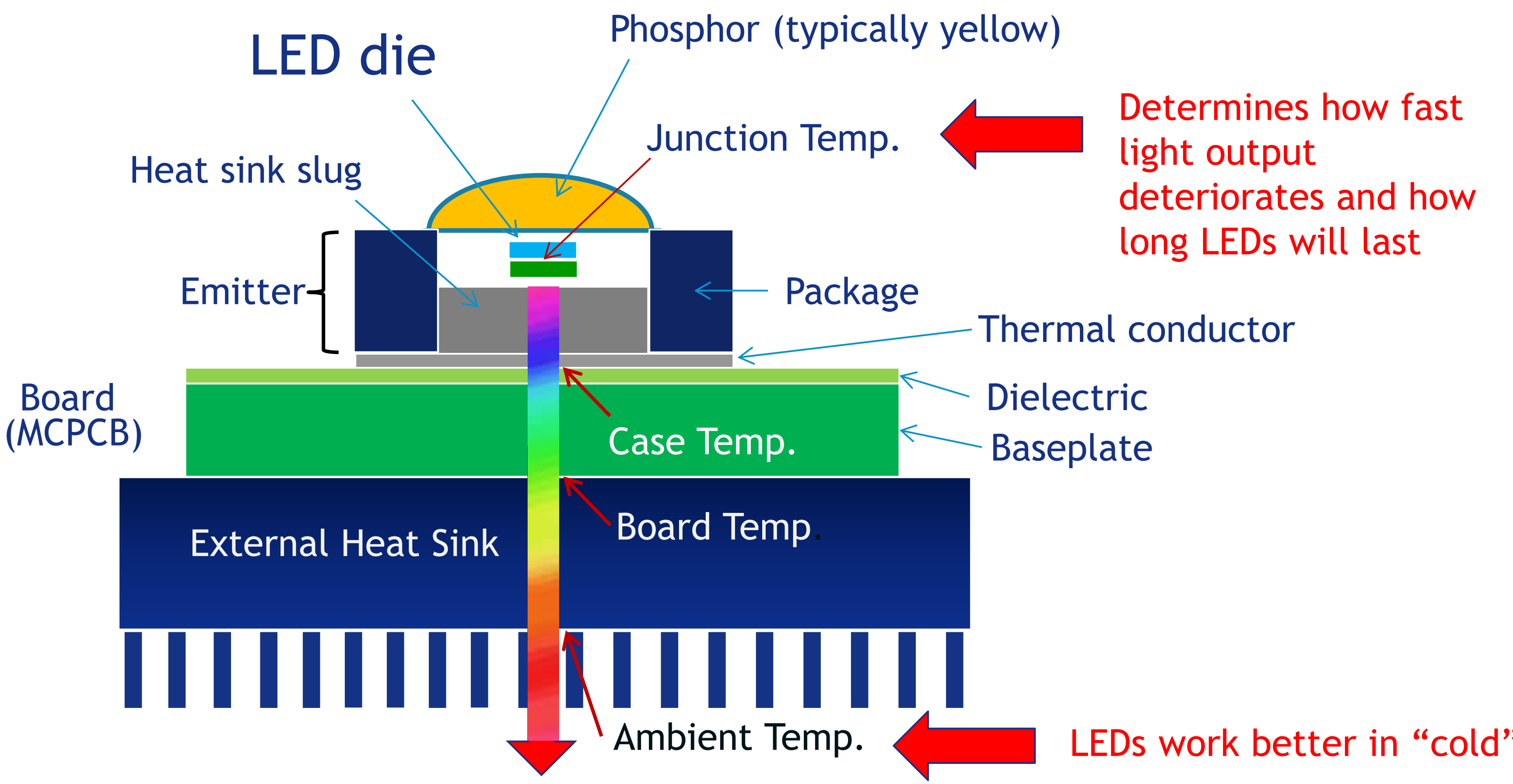
LED "Surface-mounted" Construction



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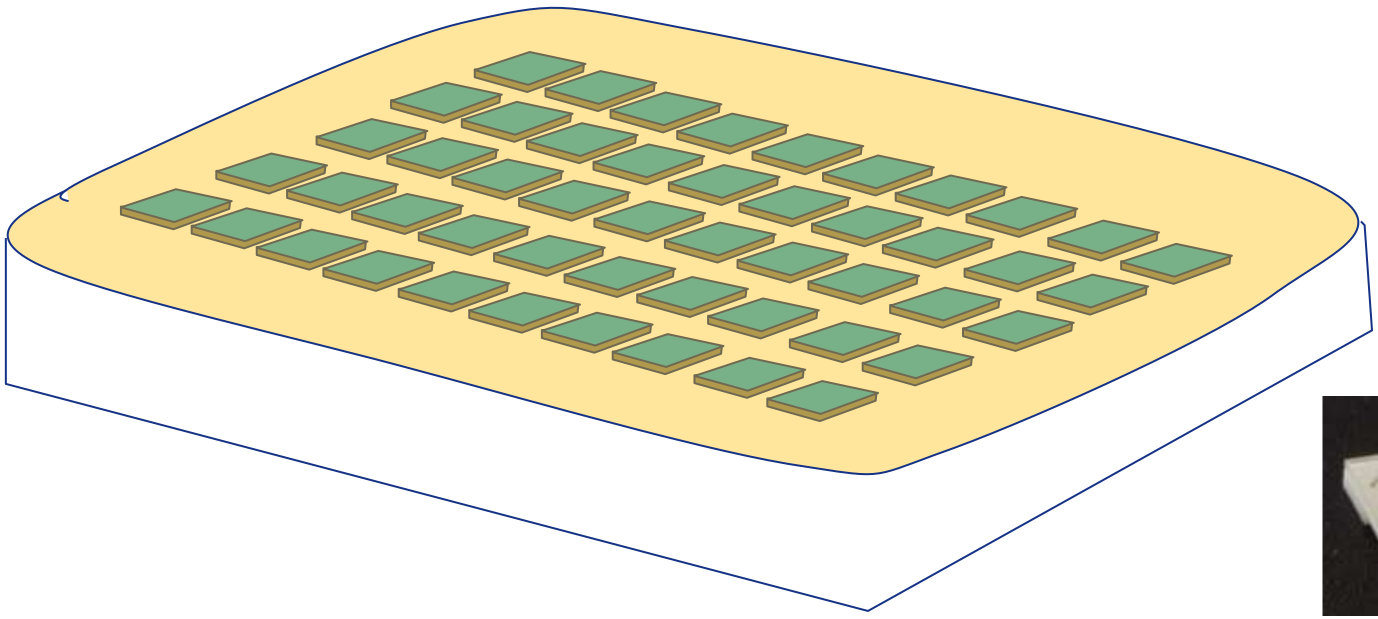
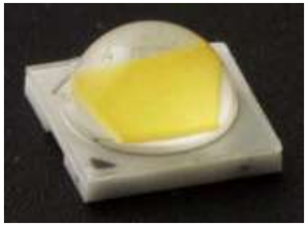
LED "Chip-on-board" Array



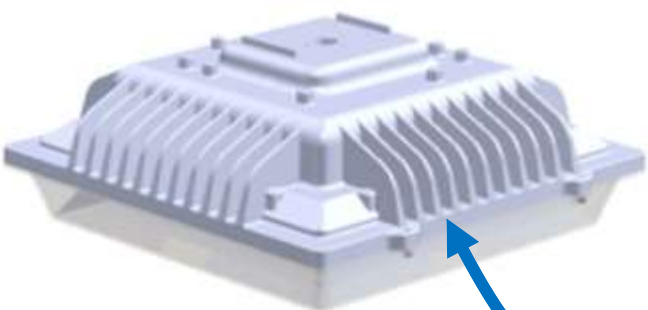


- Multiple individual LED dies connected in series to create a high voltage array LED. ~5000 lumens
- High voltage → low current → high efficiency drivers

Lower Junction Temperature (crucial)

Better Lumen Maintenance

Longer Life



Heat Sinks (outside)

Thermal Conduction (inside)

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LED Drivers

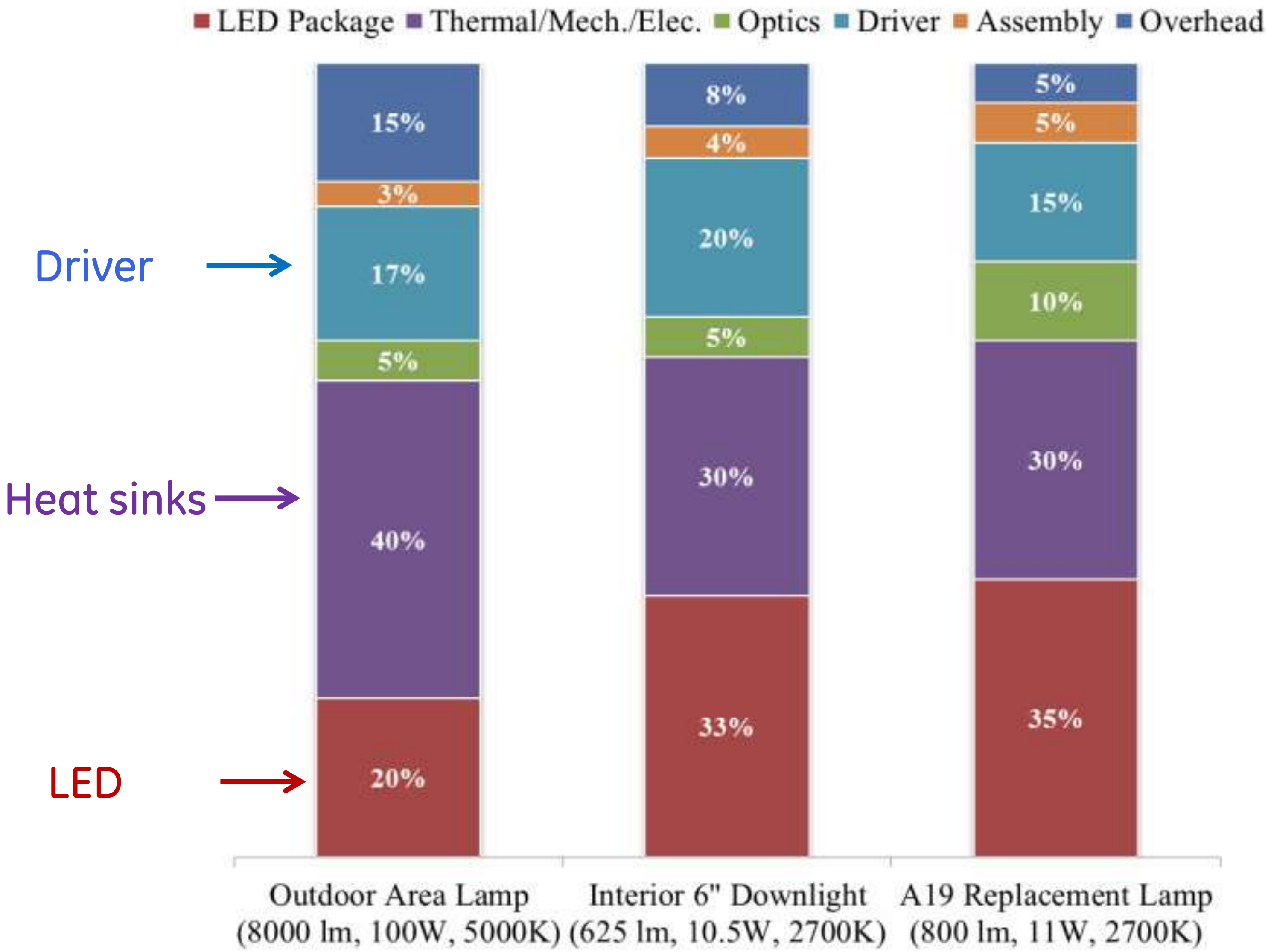
- Individual LEDs operate on low voltage d-c
- Drivers have to be matched to the LEDs
- Dimming is achieved by reducing current
- Good engineering of drivers is critical

What is happening right now?

- LEDs have become the most efficient light source in 2013
- Consumer product pressure to get items on shelves is causing prices to fall faster than costs are falling—imbalance.
- Issues with LED dimming: some resolved but some still persist
- Color-changing LEDs are possible but question remains on how the general lighting market will embrace this
- High CRI (90+) available for a 15% penalty in LPW
- High power array LEDs available but lack optical control, challenge for thermal management
- Electricity prices have stayed steady because of fracking and shale-oil energy sources, affected adoption of LEDs

2014 Expectation 1:
LED chip costs will continue to go down but begin to flatten out

- Chips will continue to lower in price because of larger dyes and better yields, automation
- New cost savings have to come from components and processes:
  - Optical system
  - Heat sinks
  - Drivers
  - Automated assembly
  - Streamlined testing
  - System flexibility



Source: DOE SSL Roundtable and Workshop attendees

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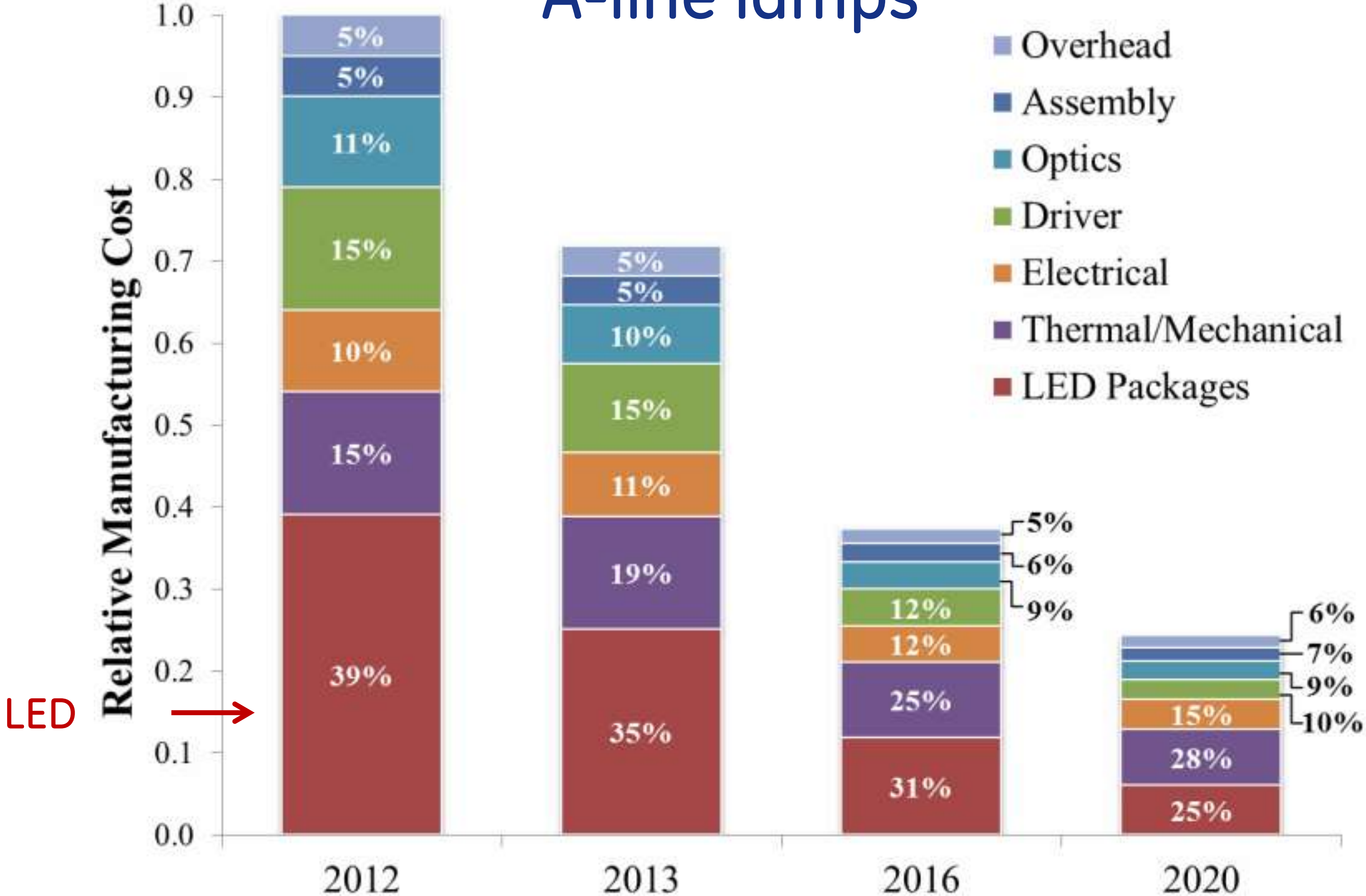
A-line lamps



Source: DOE SSL Roundtable and Workshop attendees

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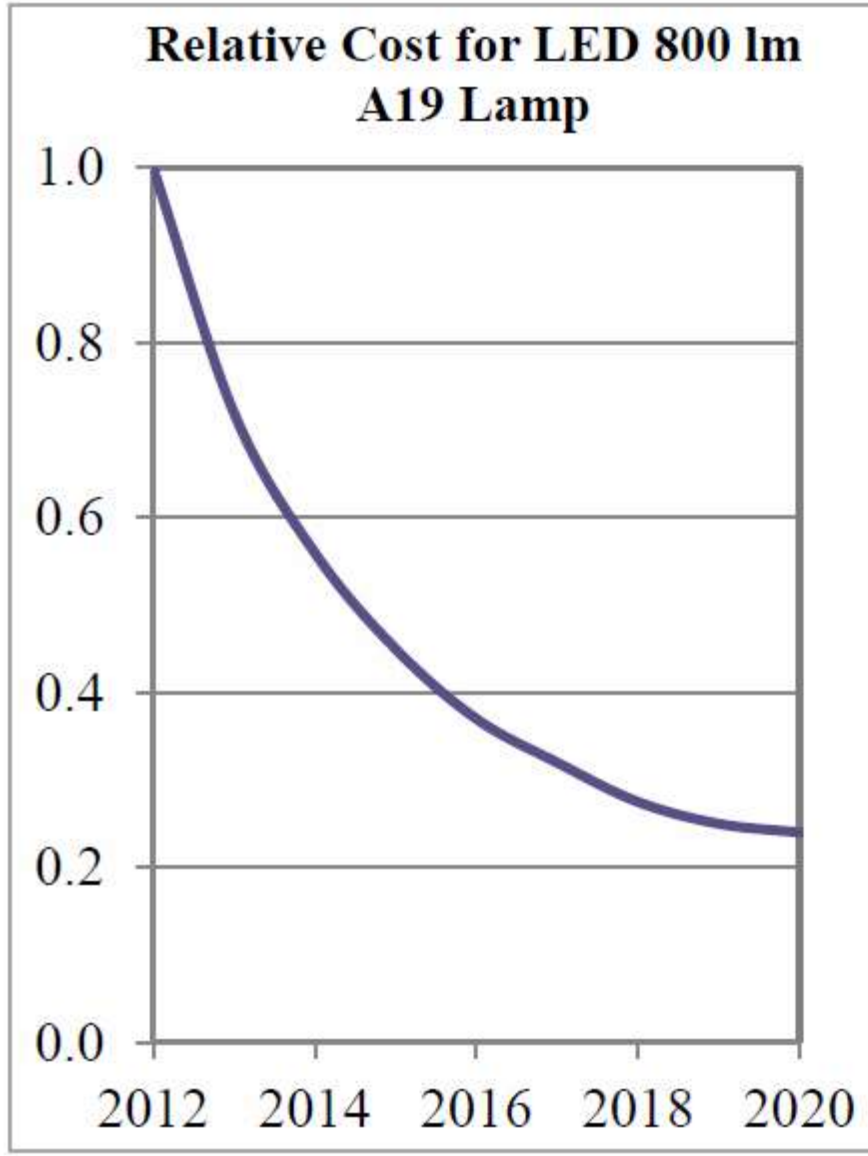
Consumer LED lamps

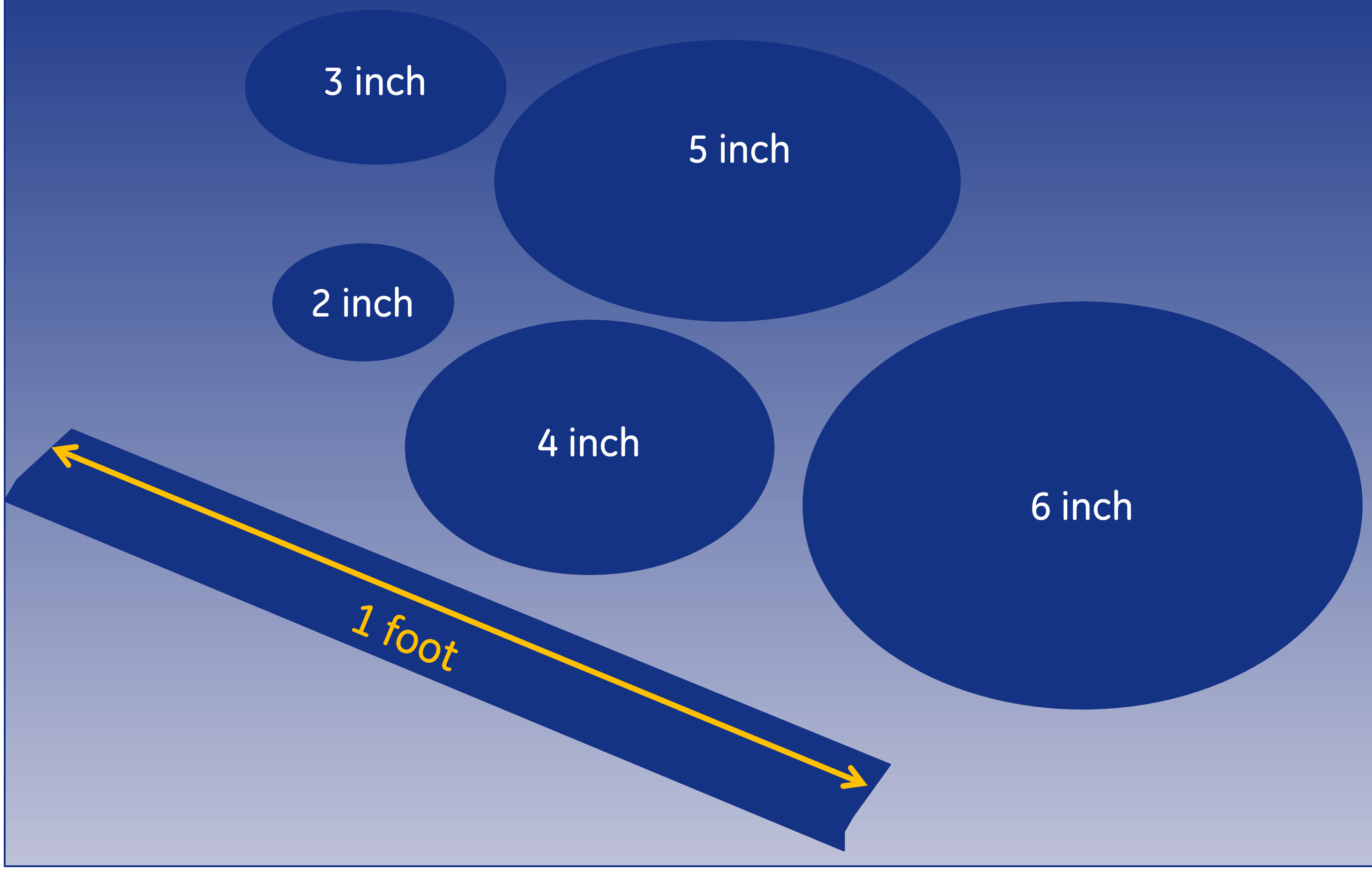
- Prices have been falling faster than costs because of competition for shelf space at retailers

- Reliability issues will continue to surface with lower quality product

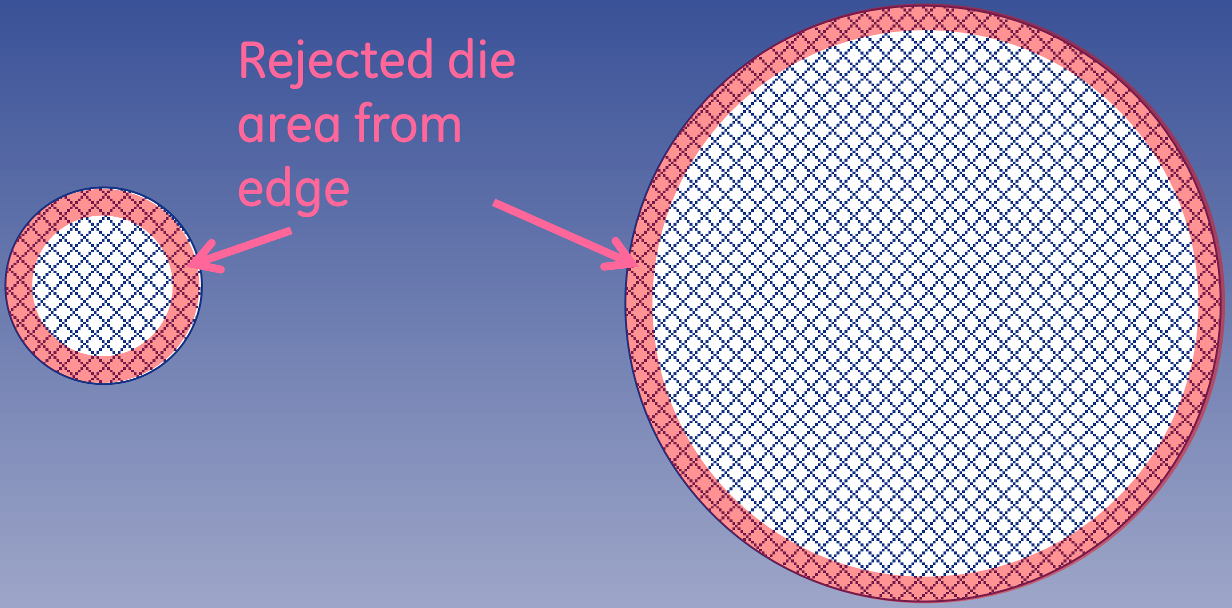


http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_manuf-roadmap_sept2013.pdf

Better yields, better uniformity of LED dies



As wafer sizes have increased, yield from "good area" has also increased



LED Prices for mid- and low- power LEDS will fall faster because of overcapacity

- Large capacity created for mobile devices, back-lit displays will now be used for general lighting

2014 Expectation 2: Increased LPW, better color control

LED Efficacy Compared to Conventional Lighting Technologies	
Product Type	**Luminous Efficacy (in lm/W)**
LED A19 lamp (warm white)	94
LED PAR38 lamp (warm white)	78
LED troffer 1'x4' (warm white)	118
LED high/low-bay fixture (warm white)	119
High intensity discharge system (high watt)	115
Linear fluorescent system	108
High intensity discharge system (low watt)	104
Compact fluorescent lamp	73
Halogen	20
Incandescent	15

Source: **2013 DOE SSL Multi-Year Program Plan**

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2014 Expectation 3:
Reliability concerns will make customers more quality conscious

- **LED life currently based on light output**

… but other failure modes exist:

- Driver component failure
- Material degradation
- Plastic yellowing
- Solder joint breakage
- Thermal conduction deterioration

LEDs Reliability

Issued: August 2013

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

Building Technologies Program
SOLID-STATE LIGHTING TECHNOLOGY FACT SHEET

Lifetime and Reliability

Long life has been billed as a key advantage of LEDs, but understanding and communicating how LED products fail and how long they last can be challenging. While LED-based products hold the potential to achieve lifetimes that meet or exceed their traditional counterparts, manufacturer claims can be misconstrued by users who do not fully understand LED product failure mechanisms or the difference between lifetime and reliability.

Introduction

All lighting products fail at some point; that is, they reach the end of their useful life. Under normal use and conditions, product failure results from design flaws, manufacturing defects, or wear-out mechanisms. The familiar bathtub curve (Figure 1) shows how failure rate typically changes over the life of a product.

For conventional, lamp-based lighting systems (e.g., incandescent, fluorescent, and high-intensity discharge), failure most

Conclusion

"As LED technology matures, some of the current issues surrounding the measurement and reporting of lifetime and reliability may abate. **However, it is likely that products will continue to fail both catastrophically and parametrically, through various mechanisms**. The dependence of LED package performance on other components will continue to require that discussions about lifetime be focused at the luminaire, and not component or even lamp level, as lamp performance in different luminaires can vary. Innovative luminaire designs and control strategies—such as variable drive products that maintain lumen output—will further complicate the measurement and reporting of lifetime. As with many performance attributes, LEDs have the potential to best other technologies in terms of longevity, but choosing the right product requires some understanding of expected failure mechanisms, lifetime, reliability, and serviceability, as well as asking the right application-specific questions."

From: http://www1.eere.energy.gov/buildings/ssl/what-to-ask.html

What to Ask

Below are some helpful questions for lighting designers and specifiers to ask when evaluating LED lighting products. Also be sure to look for products that are registered with **LED Lighting Facts®.**

Input/Output

What are the delivered lumens at each correlated color temperature (CCT)? (Note that flux and efficacy usually vary with CCT.)
What is the real input power?
Do you have LM-79 photometric reports and IES files from an independent testing lab?

Color

What is the color rendering index (CRI) at each color temperature?
How do you ensure color consistency among fixtures built today or a year from now? Do you have test data demonstrating color stability over time?
Does the thermal management system keep the LED junction temperature below specified maximums in all applications?
May I see at least two samples of the same CCT?
Were your chromaticity measurements performed according to LM-79 by an independent lab? (Be sure the lab is accredited by the National Voluntary Laboratory Accreditation Program or CALiPER-recognized.)
Is there a written color binning policy?

Life/Warranty

Is there a written end-of-life policy, and how will spares be made available?
How long is the warranty? What exactly is covered?
Has LM-80 testing been performed by your LED or LED module manufacturer? What does it say about lumen maintenance?
Do you have test data to verify that your system operates at a temperature and drive current consistent with those LM-80 test results?
Is the expected life of the driver different from the LEDs?

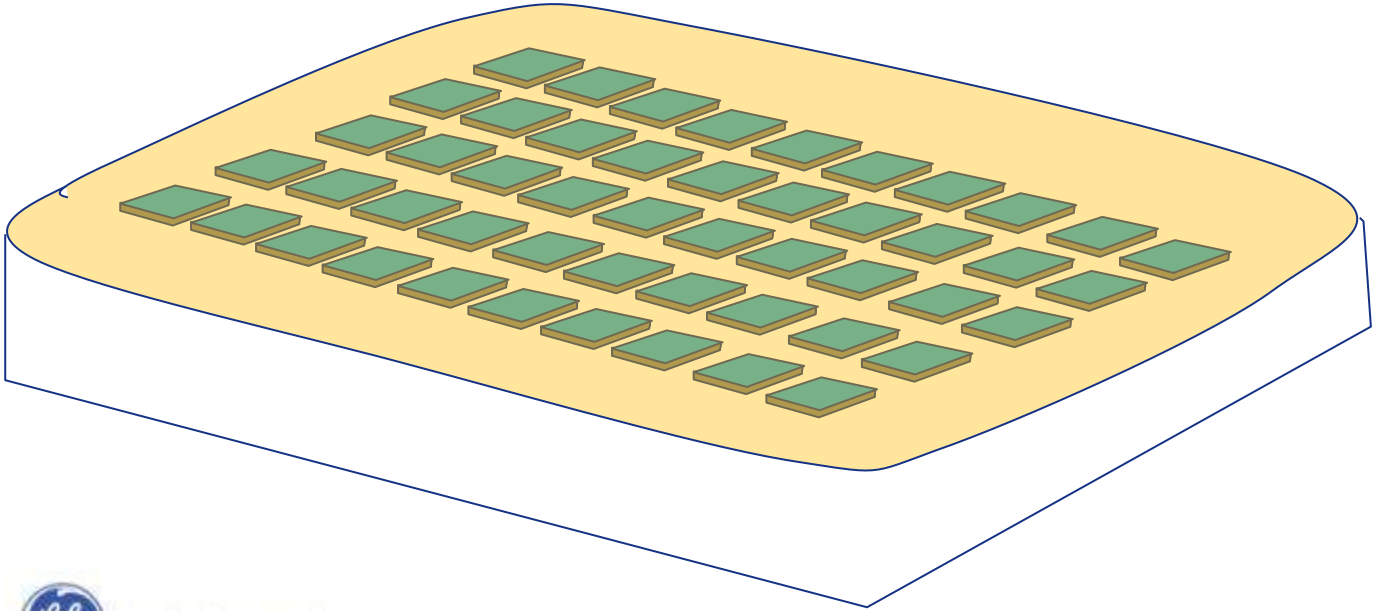
Dimming/Flicker

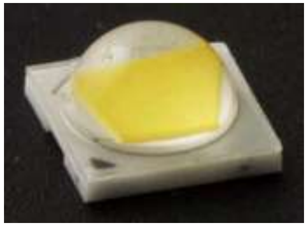
Are your luminaires or lamps dimmable?
On what kinds of dimmers? Do you have lists of compatible dimmers?
What is the dimming range? To 50%? To 10%?
Is dimming smooth? Linear?
Is there any visual flicker when full on or at any point during dimming?
What is light output frequency and depth of modulation?
Is there color shift during dimming? Which direction?

2014 Expectation 4:
Smaller packages, higher brightness, less watts

2014 Expectation 5:
High-lumen, high-voltage LED arrays

- Ceramic (Aluminum Nitride substrates)
  - More expensive but better heat conduction
- High voltage allows drivers with 95% efficiency instead of 80% to 90%





2014 Expectation 6:
Economic perspectives; cost-benefit analysis improving

- Industry will realize that overall cost of ownership is important, not simple payback
- Fluorescent office ceilings still challenging, upgrade must be based on life-cycle costs rather than simple payback

2014 Expectation 7:
Significant advances in drivers and controls

- 90% – 95% efficiency possible
- Dimming will become almost “standard” with LED fixtures
- Wireless control on the rise

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2014 Expectation 8:
Activity in intellectual property, patents and lawsuits

- Many "cheap" and "copycat" LED businesses will find the going harder
- Major players will try and capitalize on intellectual property
- Innovation will be rewarded

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2014 Expectation 9:
Innovative LED sources will appear

- 1st generation: novelty items (keychains, etc.)
- 2nd generation: replacement lamps
- 3rd generation: replacement fixtures
- 4th generation: Totally new light sources

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