Reinventing Lighting

DOE SSL R&D Workshop
Jan. 27, 2015

John Edmond
Cree, Inc. Co-Founder and
Director, Advanced Optoelectronics Technology

Company Mission

Outline

- Fundamental Approach
- LED Milestones
- LED Chips and Components
- The light bulb: Edison to LEDs
- LED General Lighting
- End Results: Jobs!

Outline

- **Fundamental Approach**
- LED Milestones
- LED Chips and Components
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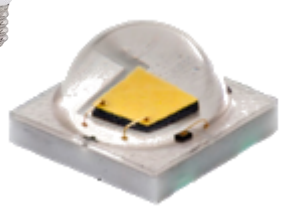
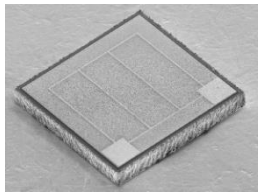
Vertical Integration

Lamps, Luminaires

Phosphor & Component Packaging



LED Chips



SiC Wafers

Materials

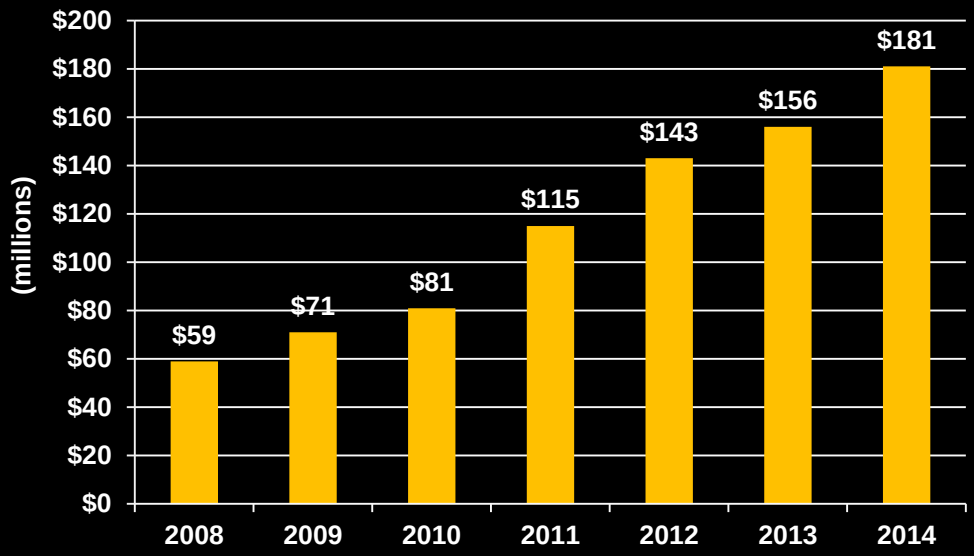
Approach

- Innovation and Technology drive actions at every level
- Vertical Integration enables end-to-end optimization

Result

- Best in class performance and cost
- Best customer experience and Quality

Innovation requires a lot of work and R&D dollars



Note: All totals include exclusively licensed patents	Issued Patents	Pending Applications
U.S.	1,491	998
Non-U.S.	2,596	2,143
TOTAL	**4,087**	**3,141**

Cree Businesses

Outline

- Fundamental Approach
- **LED Milestones**
- LED Chips and Components
- The light bulb: Edison to LEDs
- LED General Lighting
- End Results: Jobs!

LED Milestones Timeline

1987

Cree founded
NC State Univ.

Started with 6-Guys 1987

LED Milestones Timeline

Commercialized first blue LED SiC/SiC

1987 **1989**

Cree founded

1990 Ad campaign

Electronic Engineering TIMES

This week in **The Profession**
The IEEE has analyzed the results of its '1990 Opinion Survey.' Page 61.

Monday
July 16, 1990
Issue 599

A CMP Publication

THE INDUSTRY NEWSPAPER FOR ENGINEERS AND TECHNICAL MANAGEMENT

Digital roars onto FDDI 'superhighway'

Fiber Distributed Data Interface (FDDI) network (100 Mbits/s)
DEC bridge 500
DEC concentrator 500
DEC FDDI controller 700
IEEE 802.3 Ethernet LAN
IEEE 802.3 Ethernet LAN

Digital Equipment expects FDDI to be the backbone that ties together multiple Ethernet networks. See story, page 16.

GI puts the squeeze on NTSC TV signals

By Richard Doherty

Nashville, Tenn. — General Instrument Corp. used the 1990 Satellite Business & Communications Association (SBCA) show here to demonstrate its DigiCipher NTSC channel-crunching technology. With DigiCipher, GI's VideoCipher division (San Diego) claims to have compacted a 200-Mbit/s NTSC video signal into a 3- to 4-Mbit/s digital data stream.

This is the first appearance of several expected digital-compression technologies designed to squeeze multiple NTSC TV channels into the space now occupied by only one. As more debut within the next two years, the competing technologies are likely to target the backyard satellite TV market, where the TV-bandwidth crunch is becoming especially critical—a situation that will be exacerbated by the advent of HDTV, which requires about five times the spectrum that NTSC does.

Among others working on digital compression are the team of Starscan and Compression Labs, and the Sky Cable group, which includes Rupert Murdoch, Hughes, NBC and Cablevision.

GI's DigiCipher is able to compress up to five NTSC programs from a single TV broadcast or cable channel, or pluck up to 10 NTSC signals from a single satellite transponder. The system piggybacks data services and at least two CD-quality audio channels on the video signal.

This technology is a variant of the DigiCipher HDTV-compression scheme that GI petitioned the FCC with as a standard five weeks ago (see June 11, page 25). Both the NTSC and HDTV DigiCipher versions are extensions of the GI VideoCipher II audio and data compression system, which is already installed in millions of home satellite dishes.

Since the NTSC and HDTV DigiCipher compression technologies are related, General Instrument could introduce a set-top decoder that could receive both signal types, regardless of whether they arrive via satellite, cable or terrestrial antenna. GI claims

Continued on page 14

Euro TVers plan HDTV programs

By Roger Woolnough

Strasbourg, France — Europe's TV hardware and software companies are collaborating in a $145 million project to build up a bank of program material to be ready for the start of HDTV broadcasting. The move is the latest stage in an ambitious plan to ensure that Western Europe is not swamped by Japanese HDTV technology.

Already, the European consumer electronics and broadcasting industries, led by Philips (the Netherlands), Thomson (France), Robert Bosch (West Germany) and Nokia (Finland), have spent $360 million in the first phase of an HDTV hardware program under the pan-European Eureka research scheme. Now, these companies and others are preparing to

Continued on page 4

Concerned over tech transfer with Toshiba?

Moto eyes IBM DRAMs

By John Thompson and David Lammers

Austin, Texas — Motorola has turned to IBM for a 4-Mbit DRAM design to be built in its MOS 11 fab here. The deal comes after negotiations between Motorola Inc. and Toshiba Corp. of Japan aimed at exchanging DRAM and 68030 microprocessor technology reportedly fell through.

The Motorola/IBM Corp. deal is expected to include a transfer of IBM's 8-inch wafer technology, which could pave the way for Motorola's migration to 16-Mbit memory designs using IBM's design, fabrication and process technology. The move also gives a big boost to IBM's ongoing efforts to spur domestic DRAM manufacturing.

An IBM/Motorola 4-Mbit DRAM technology agreement would signal an important shift in Motorola's DRAM manufacturing strategy, but it does not mean an end to a continuing Toshiba/Motorola joint-manufacturing agreement that covers Toshiba's DRAMs, and which is being expanded to include Motorola's 88000 microprocessor, but not the long sought-after 68000 line.

The two companies have a technology-exchange agreement that has led to Motorola's entry into the 1-Mbit DRAM business. To that end, the two started a joint-manufacturing plant, Tohoku Semiconductor, in Sendai, Japan.

What is significant about the latest memory-sourcing developments, industry analysts said, is the shift in technology exchange between Motorola and Toshiba: what was to have been a corporate-wide exchange of process and device fabrication technology between the world's second- and fourth-largest semiconductor makers is now being tightly restricted within the framework of the existing Tohoku joint venture.

Competitive fears surrounding direct technology transfer have effectively scrapped expansion of the Motorola/Toshiba relationship, which would have seen the partners swap their respective technologies directly rather than invest them in the joint venture.

Late last year, Motorola reported that it planned to transfer a Toshiba 4-Mbit DRAM process into its MOS 11 fab sometime this year. This was part of a joint-manufacturing deal, said to include the possible transfer of Motorola's 32-bit 68030 microprocessor technology to Toshiba (see Nov. 13, 1989, page 2). Since then, Motorola has reportedly become averse to such a broad technology exchange, and it sees a linkup with IBM as a better alternative to expanding its DRAM production.

Continued on page 8

NACS sees R&D gap in IC-gear biz

Ian Ross: Heads NACS.

By Brian Robinson

Washington — The new National Advisory Committee on Semiconductors report predicts a drastic collapse in the American share of the semiconductor equipment and materials market if $1.2 billion in R&D funding is not injected during the next three years. Whether or not this happens will have major consequences for the U.S. semiconductor industry, and the ball

Continued on page 72

ANALYSIS

Active-matrix displays will lead the way

The flat-panel surge

By David Lammers

Flat-panel displays will overtake CRTs as the leading display technology sometime in the mid-1990s, as manufacturers overcome production hurdles for active-matrix liquid-crystal displays, predicted participants at a recent LCD manufacturing seminar held here.

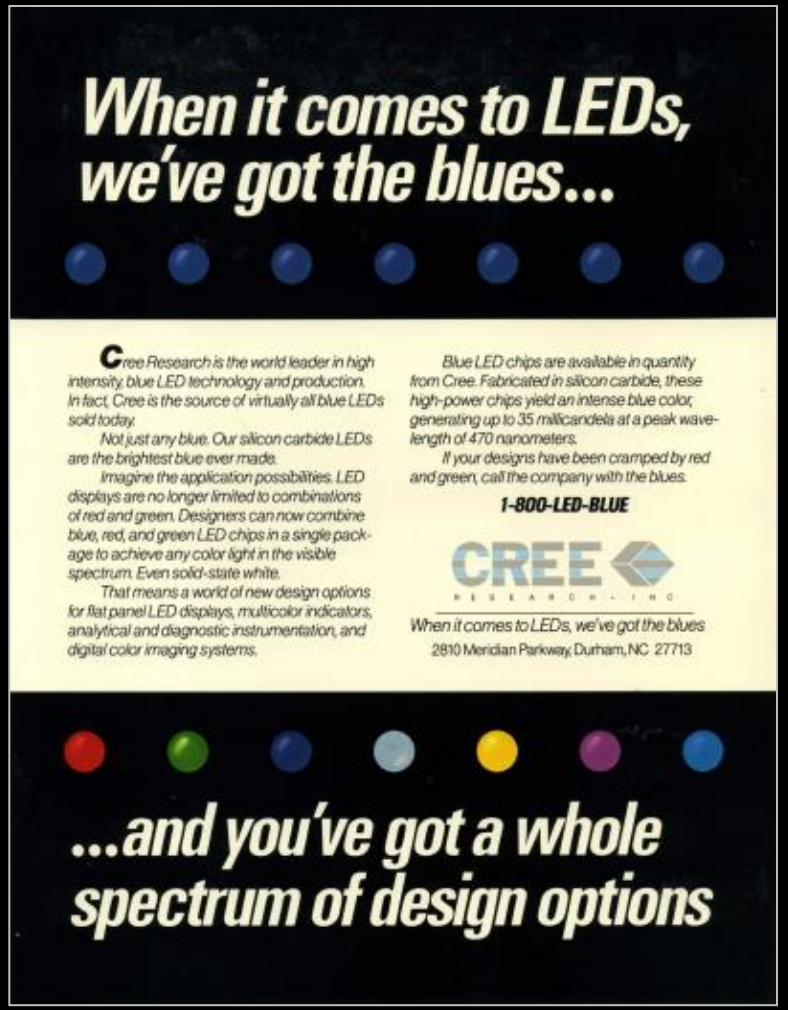
Several LCD manufacturers are slated to bring 10-inch active-matrix color LCDs to market this year, albeit at stiff prices. At the Semicon Kansai seminar, Sharp Electronics Corp. and Toshiba Ltd. demonstrated 14-inch prototypes that featured excellent color and response times, though some panels were marred by faulty pixels.

Many observers expect dramatic improvements in both cost and quality within the next few years, however. At Semicon Kansai, analysts from market watcher Jardine Fleming Securities predicted that 14-inch, 600,000-pixel active-matrix color LCDs will cost as little as 15,000 yen ($100,

Continued on page 74

Flat-panel sales forecasts vary widely, but many see these displays overtaking CRTs by the middle '90s.

INSIDE



First RGB Full Color Display (1993)

LED Milestones Timeline

1987 — Cree founded

1989 — Commercialized first blue LED SiC/SiC

1995 — SiC/GaN Blue LEDs designed into VW Dashboard

2002 — Introduced first XBright® LED power chip

2004 — First XLamp LEDs brought to market 50 LPW

DOE "White LED Dev. for General Illumination Applications" (10/00-10/04)

2006 — First "Lighting-Class" LED components 100 LPW

DOE "High Efficiency LED Lamp for Solid-State Lighting" (10/03-12/06)

2007 — First commercially-viable LED downlight and LED streetlight

2009 — First commercially-viable LED PAR Lamp

DOE "An Integrated Solid-State LED Luminaire for General Lighting" (10/06-9/08)

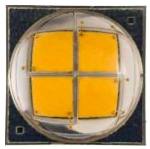
LED Milestones Timeline

Commercially available white LEDs exceed 150 LPW

First to achieve >150 LPW LED lamp

SC³

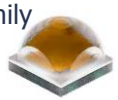
Redefined LED price & performance with new Cree SC³ Technology Platform



Commercially Available white LEDs exceed 200 LPW MKR

CXA-HD

HD Family



XPL 200 LPW

XBH

XQE

Cree Leads the Race to Replace with CXB, OSQ, and T8 LED Lamps

2010 **2011** **2012** **2013** **2014**

DOE "SSL Luminaire with Novel Driver Architecture" (7/09-7/11)

DOE "Low-Cost LED Luminaire for General Illumination" (8/12-7/14)

First 100 LPW LED parking/canopy fixture

First commercially-viable LED troffer

Cree introduces first sub $200 LED streetlight

Cree introduces the Cree LED Bulb

Cree takes control of controls with SmartCast™ Technology

SmartCast™

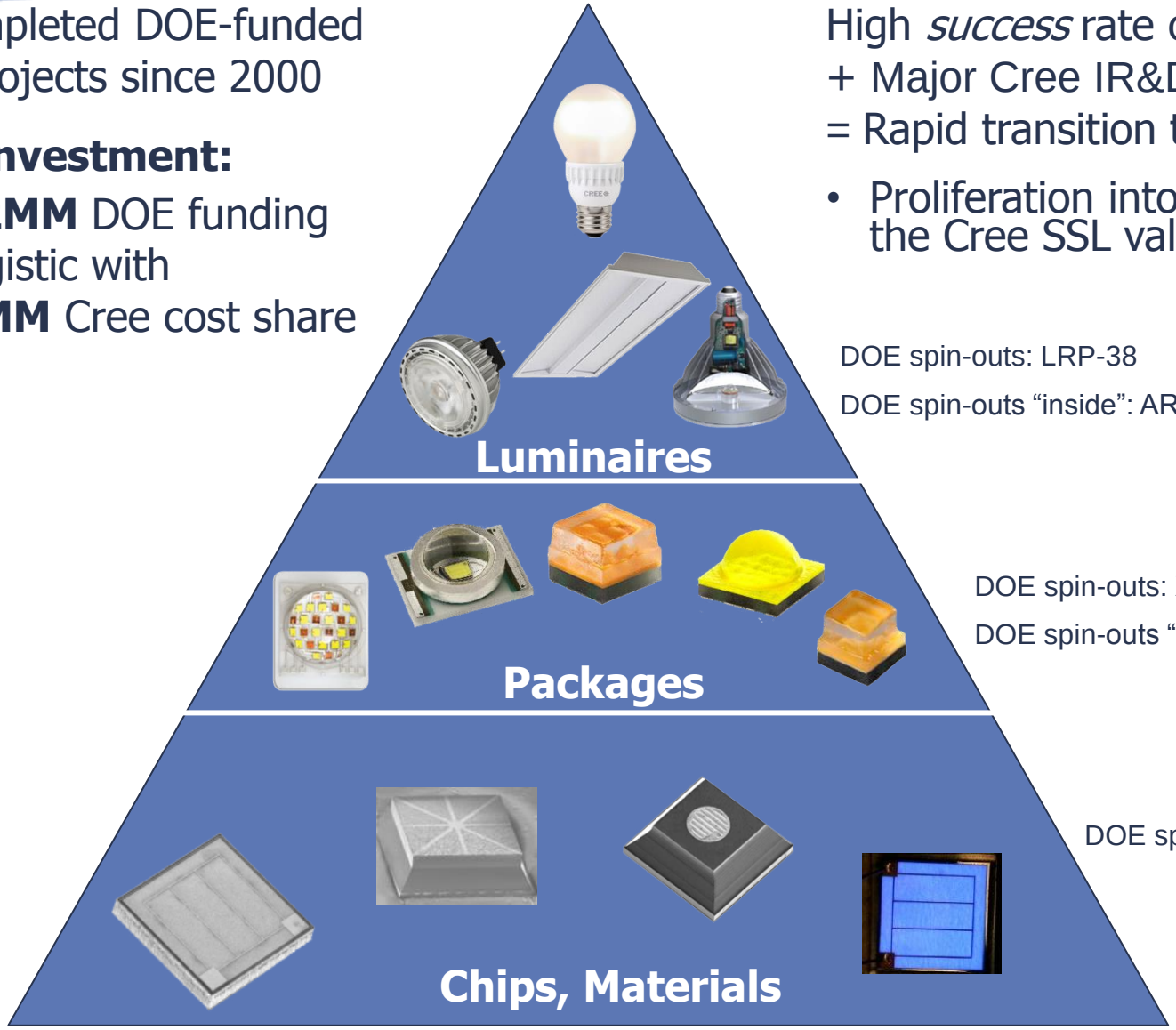
Cree is the 1st to break the 300 LPW barrier

303 LUMENS PER WATT

CREE

DOE investments in SSL R&D: high impact

- **10** completed DOE-funded Cree projects since 2000
- **Joint investment:**
  $19.2MM DOE funding synergistic with
  $7.5MM Cree cost share



High *success* rate of projects
+ Major Cree IR&D *investment*
= Rapid transition to **products**

- Proliferation into **all** levels of the Cree SSL value chain

DOE spin-outs: LRP-38

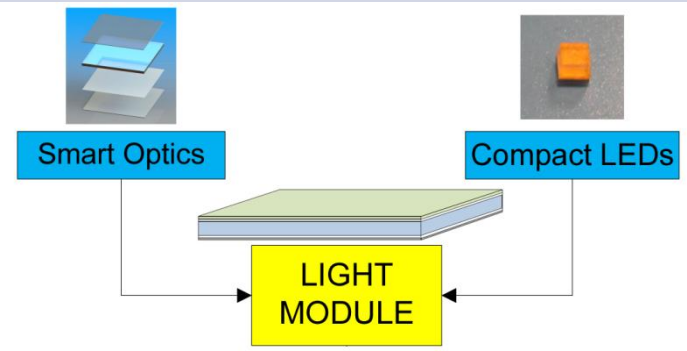
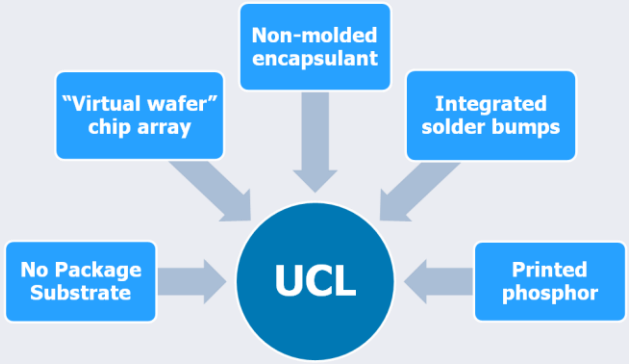
DOE spin-outs "inside": AR24, LM16, A bulbs

DOE spin-outs: XQ, XB-G/E, MPL-TW

DOE spin-outs "inside": XR-E, XP, XTE-HV

DOE spin-outs: EZ gen I, II XBright, XThin

Ongoing DOE-funded Programs @ Cree

Project	DOE / Cree Investment	Primary Focus Areas
"Scalable Light Module For Low-cost, High-efficiency LED Luminaires" (8/13-7/15)	$2.35M / $2.35M	• Compact, high-efficacy, high-CRI LEDs • Modular low-profile, cost-effective optical elements with high optical efficiency 
"Scalable, Economical Fabrication Processes For Ultra-compact Warm-white LEDs" (8/14-1/16)	$1.49M / $497K	• Ultra-compact LED (UCL) packages via new scalable, low-cost fabrication processes 

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- Fundamental Approach
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- **LED Chips and Components**
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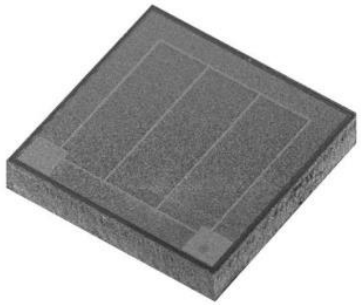
Start with a III-Nitride chip

- SiC (E_g=3.2eV)
  - Vertical current flow
    - (+) top, (-) bottom

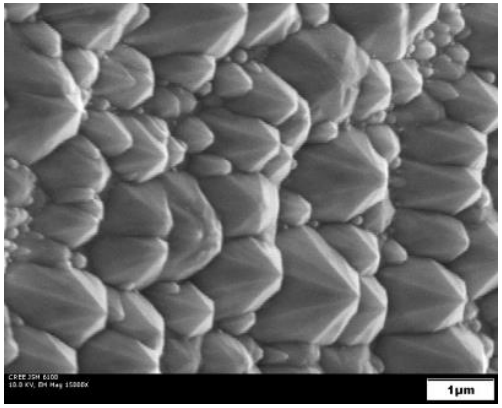
- SiC Flip
  - Lateral current flow
    - (+) and (-) on bottom

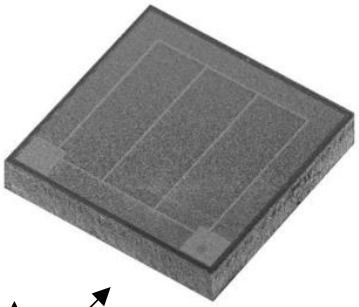
- EZ/WZ
  - Vertical current flow
    - (-) top, (+) bottom

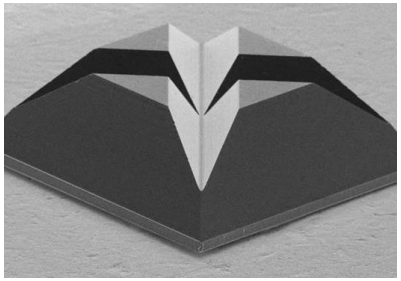


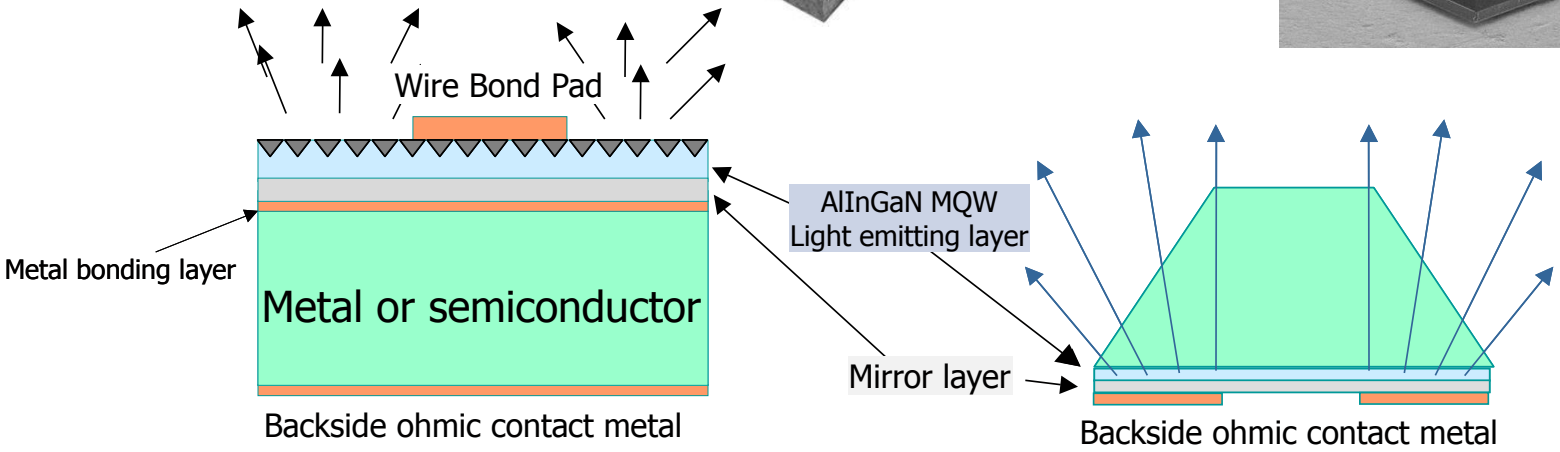
Chip Architecture Features

- **A photon is a terrible thing to waste…**
  - **Surface Features**
  - **Beveled saw cuts (SiC)**
  - **Internal mirrors**
  - **Flip-chip**

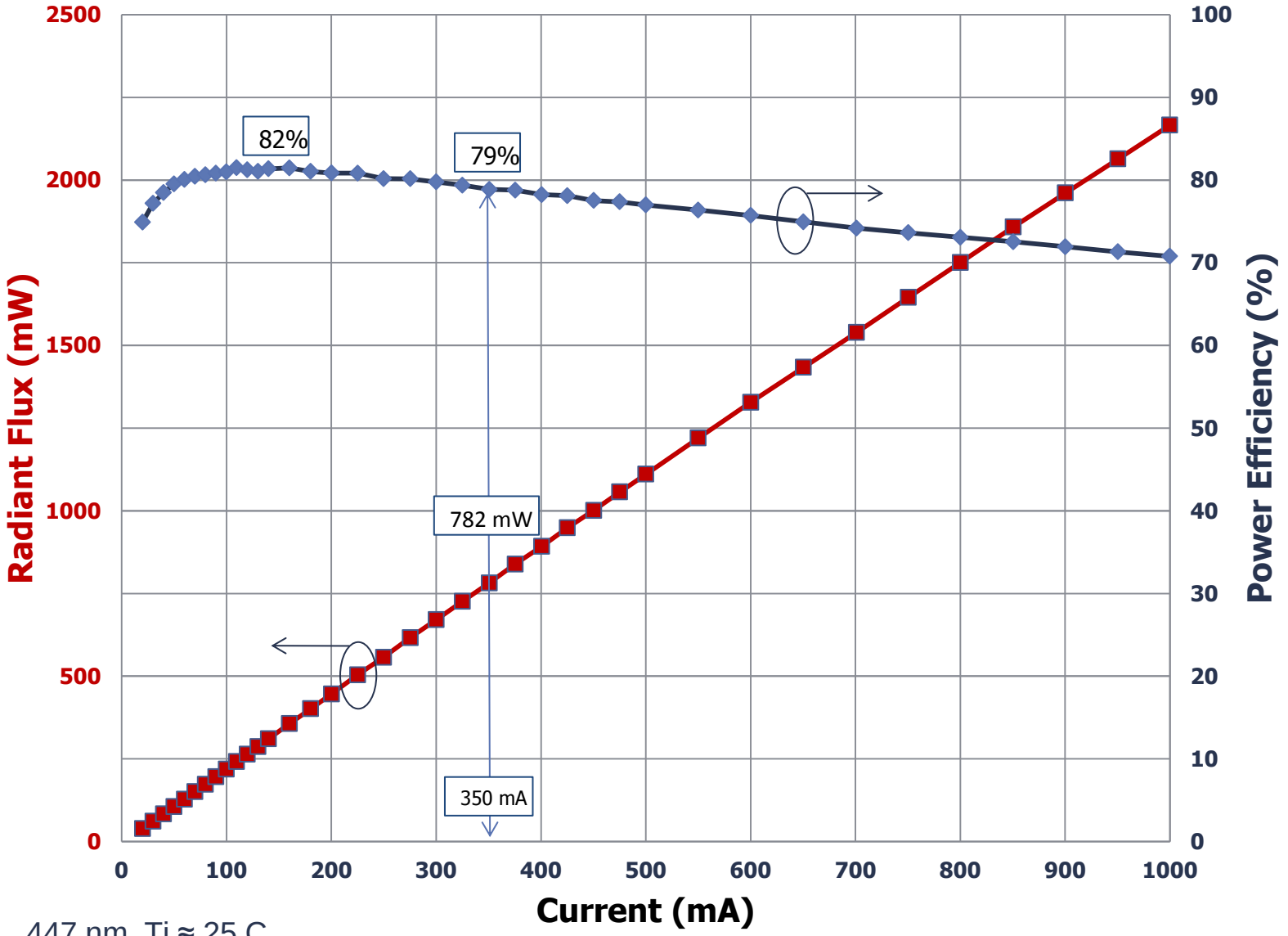








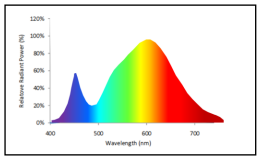
State-of-the-art Blue Chip Performance

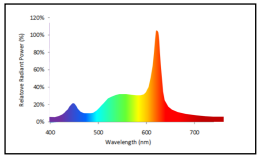


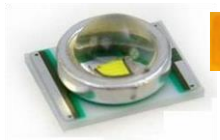
447 nm, Tj ≈ 25 C

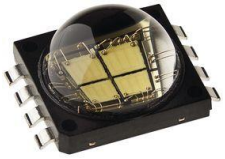
LED Chip & Component Toolbox

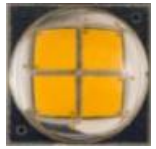
- Lenses: Glass, silicone, none
- Lead frames, molded plastic bodies, ceramic substrates, hybrids
- LP/MP/HP/COB
- HD arrays
- Modules
- CRI, spectral modifications
- BSY+R (TrueWhite™)
- High voltage topologies
- Chips:
  - Single, multiple
  - SiC, sapphire
  - tiny ←→ largest in the industry
  - Brightest epi (lm/mm^2)
  - Price/performance for any application
- Shipping hundreds of millions of units per month

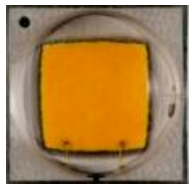




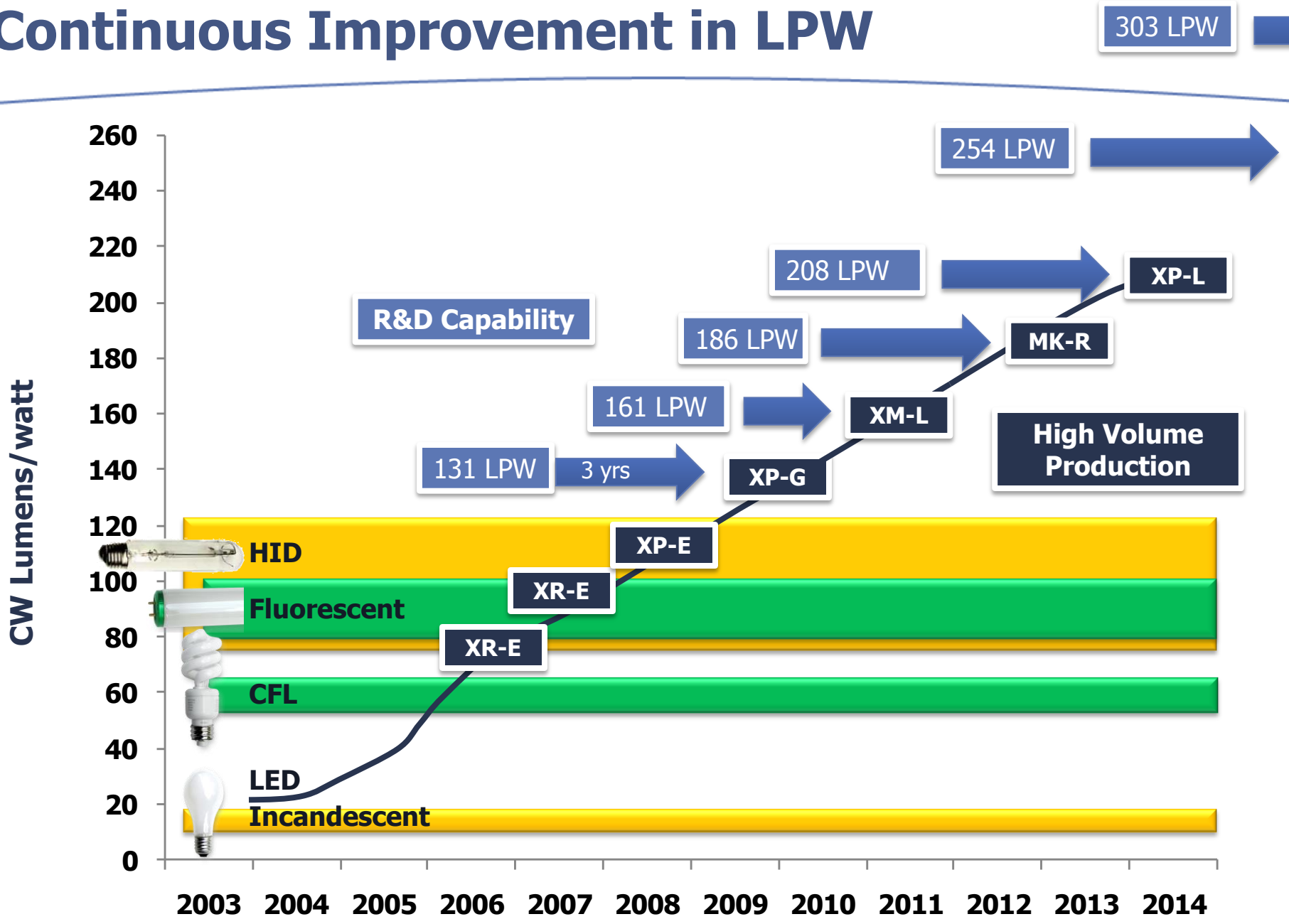




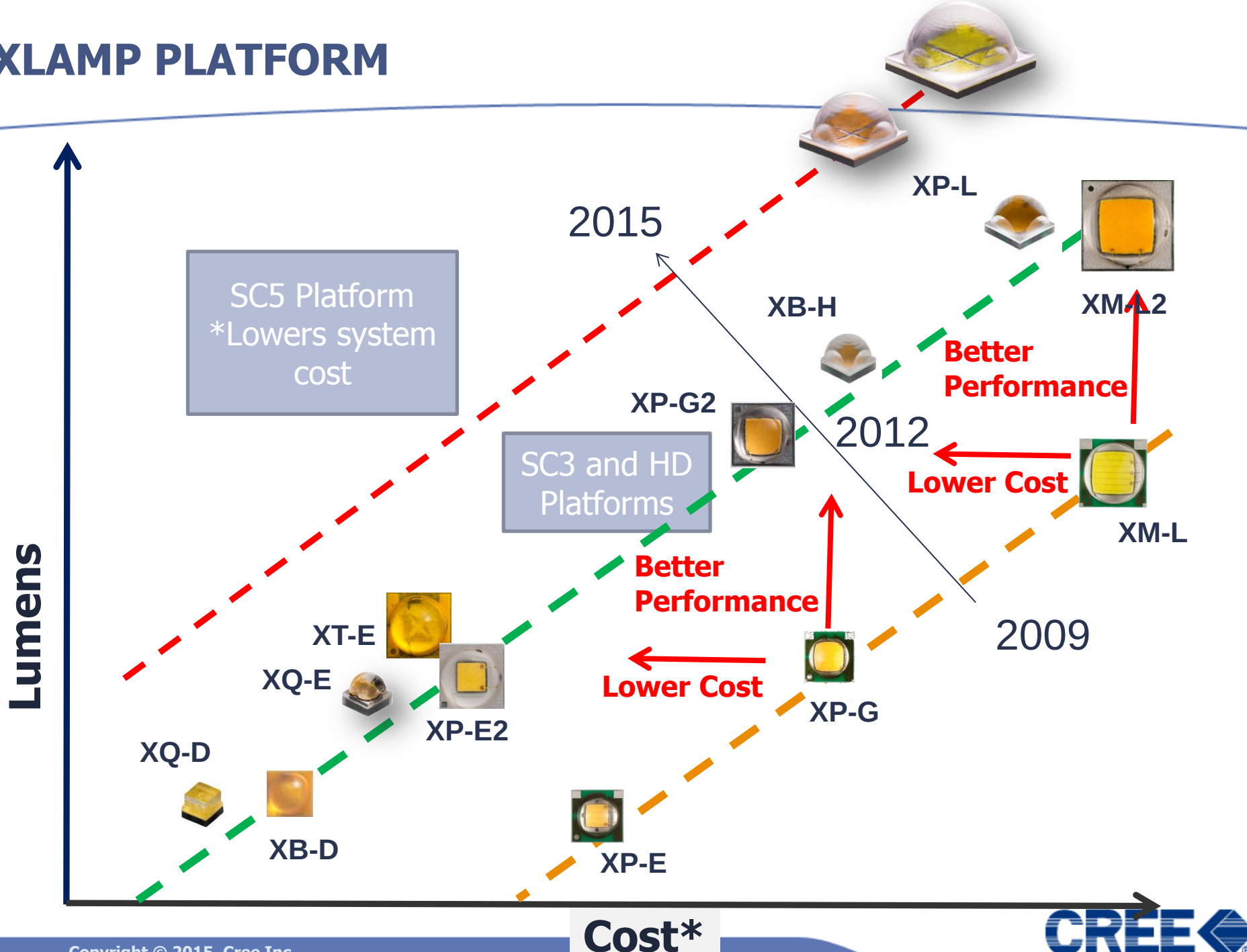




Continuous Improvement in LPW



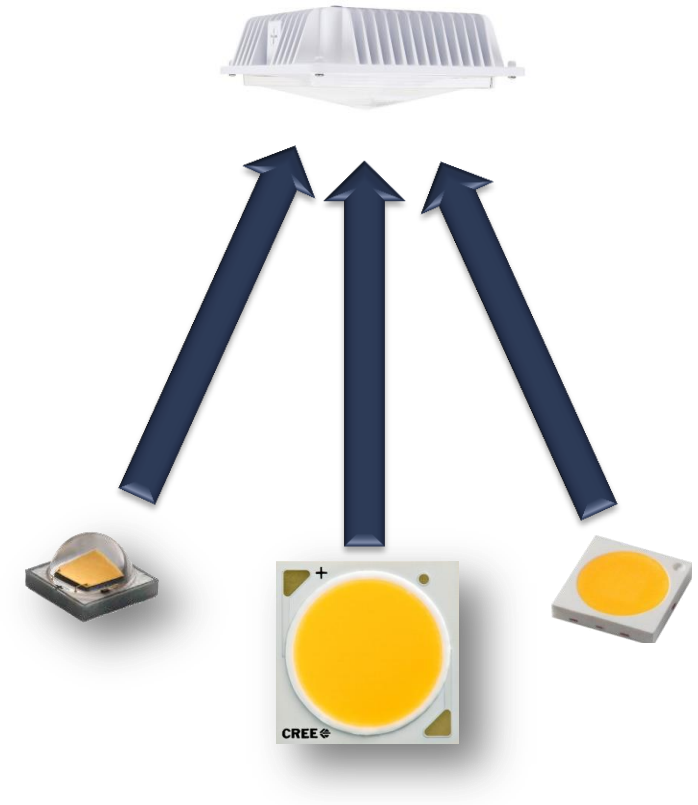
XLAMP PLATFORM



Lighting Design Philosophy: LEDs or Applications First?

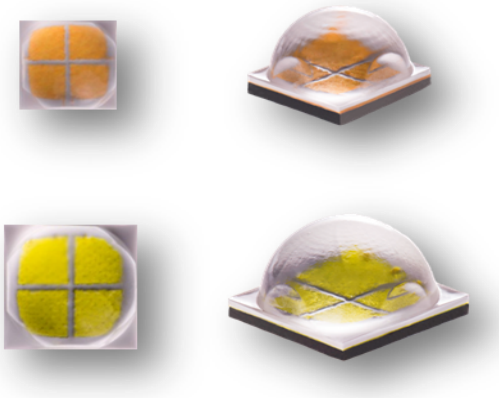
"LEDs then Application"

"Application then LEDs"



SC5 Technology Platform

Extreme High Power LEDs: XHP50 & XHP70



XLamp XHP50	Footprint:	5.0 x 5.0 mm
	Max Power:	20W
XLamp XHP70	Footprint:	7.0 x 7.0 mm
	Max Power:	30W

XHP Redefines High Power Lumen Density & Reliability to Lower System Cost

- **Double the lumens:** fewer LEDs & optics required
- **Radical system size reduction:** smaller chassis/heat sink
- **Improved long-term reliability:** reduce heat sink, not lifetime

Lighting Apps
Non-Directional
Directional
Downlight
Linear
Outdoor/High Bay
Portable

System Value of Lumen Density & Reliability

100W PAR38 Design Example

900 lumens, 40° beam, 1900 cd

LIGHTING for tomorrow

2014 Winner:
Track Lighting

30 mm

Lower
$$$

120 mm

- **Smaller PCB:** **Fewer LEDs**
- **Smaller optic:** **Best LED lumen density**
- **Fewer LEDs:** **Better lumen maintenance**
- **Smaller heat sink:** **Better reliability at high temperature**

CREE

SC5 Value: Cree Lighting High Bay Luminaire

26,000 lm

12 CXA2530 LEDs

238 W

110 LPW

Tsp = 105 C

SC5
Performance
Upgrade

42,500 lm

54 XHP50 LEDs

404 W

105 LPW

Tsp = 125 C

SC5
Further
Upgrade

46,200 lm

72 XHP50 LEDs

398 W

116 LPW

Tsp = 125 C

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…A Brief History of “Modern” Lighting

1783
Argand Oil Lamp

1810
Gas Lamp

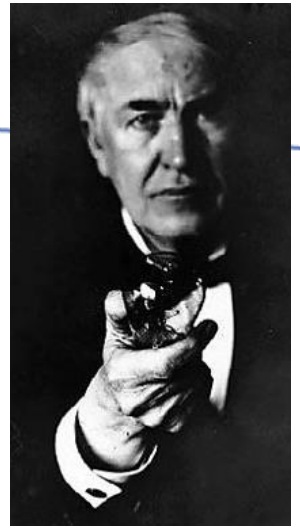
1826
Limelight

1879
Edison Light Bulb

1938
Fluorescent Tube

- **Current lighting technology is ~ 100 years old!**
- **It’s time for some innovation, ie LEDs !!**

Edison Quote



- **Regarding Edison's competition**
  - **"gas lighting is (1) almost entirely heat and only incidentally a little light, (2) not to mention evil and a vile poison"**

- **Incandescents meet criteria 1**

- **Fluorescents meet criteria 2**

The solution to both is LEDs!

Consumer - Some A19 Bulbs non-Cree

CRI~80

Target bulb segment

- 40W/60W/75W/100W+ Omni-directional
- ANSI form factor bulb
- Light weight (~110g)
- Low Cost

3M A19 Lamp

- 800 lm, 3000K, omni-directiona
- Retail: $19 at Walmart
- Assembled in USA (Minnesota)

Best Buy Insignia A19 Lamp

- 450/800 lm, 3000K, omni-directional
- Retail: $14/$17
- Weight: 100g

GE A19 Lamp

- 450/800 lm, 3000K, omni-directional
- Retail: $15/$20
- Weight: 100g

ENERGY STAR

Philips A19 Lamp

- 450/800/1100/1600 lm
- 2700 K, omni-directional
- Retail: $12/15/20/24

ENERGY STAR

CREE

Cree A19 LED Bulb

$9.97 $7.97

- ✓ Non-weird Shape
- ✓ Non-weird Color
- ✓ Pays for itself

$56.82
Was ~~$77.82~~ Save 27%

Cree 60W Equivalent Soft White (2700K) A19 Dimmable LED Light Bulb (6-Pack)

Model # BA19-08027OMF-12DE26-2U100

$69.88

Cree 65W Equivalent Soft White (2700K) BR30 Dimmable LED Flood Light Bulb (4-Pack)

Model # BBR30-06527FLF-12DE26-1U100

$21.97

Cree 30/60/100W Equivalent Soft White (2700K) 3-Way A21 LED Light Bulb

Model # BA21-16027OMF-12WE26-1U100

$71.91

Cree 90W Equivalent Bright White (3000K) PAR38 47 Degree Flood Dimmable LED Light Bulb (3-Pack)

Model # BPAR38-1503047T-12DE26-1U100

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Figures of Merit For General Lighting

- **Correlated Color Temperature (CCT)**
  - The "shade" of white from yellowish (warm) to bluish (cool)
- **Color Rendering Index (CRI)**
  - How "true" object colors appear under "white" illumination
    - By definition CRI=100 for incandescent illumination
- **Vividness**
  - Color saturation relative to the blackbody
- **Lumens**
  - Brightness of a light source
- **Lumens/W**
  - How bright the light is divided by the power to create it ie., efficiency of the light source

Figures of Merit For Lighting

- **Correlated Color Temperature (CCT)**
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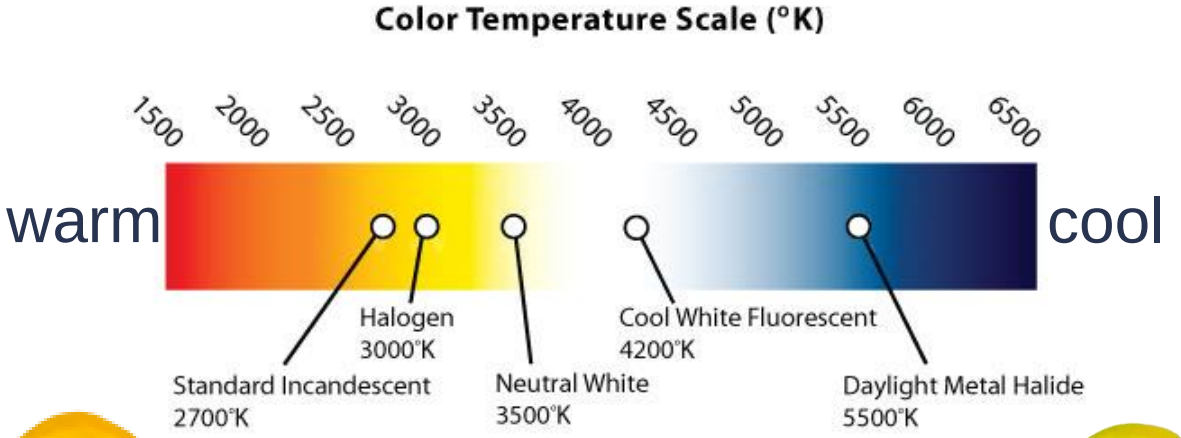
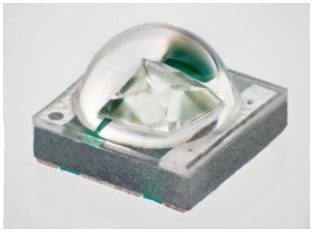
  - Color saturation relative to the blackbody
- **Lumens**
  - Brightness of a light source
- **Lumens/W**
  - How bright the light is divided by the power to create it ie., efficiency of the light source

Common Warm and Cool Sources

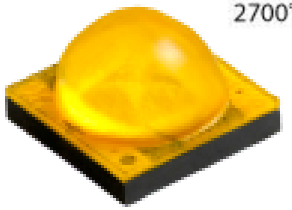
Color Temperature



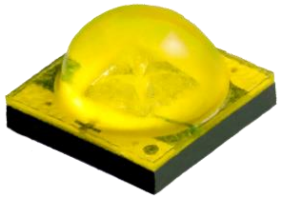
LED Approach



440-460 nm blue



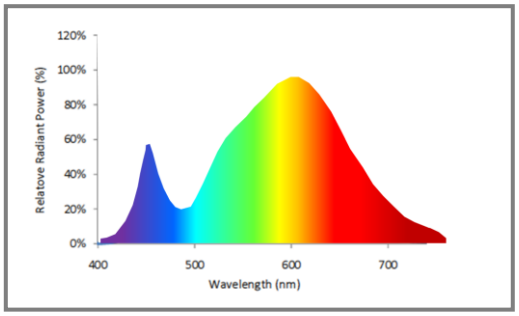
\+ or +

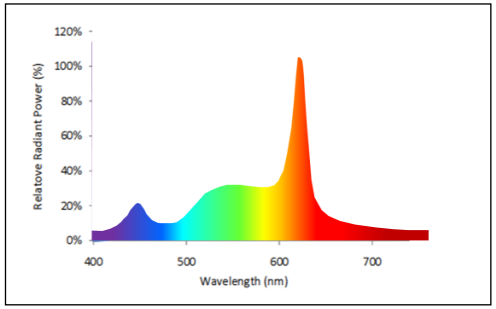


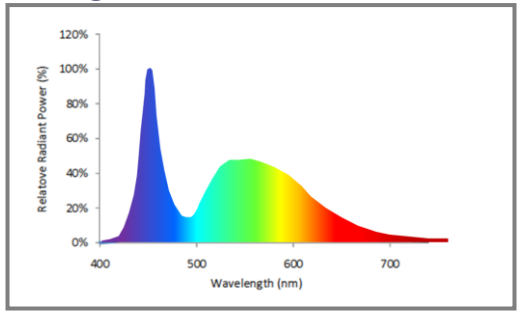
Nitride-based red phosphor

Red LED

Yttrium or lutetium aluminum garnet
Yellow-green down conversion







Cree TrueWhite™

Figures of Merit For Lighting

- Correlated Color Temperature (CCT)
  - The "shade" of white from yellowish (warm) to bluish (cool)
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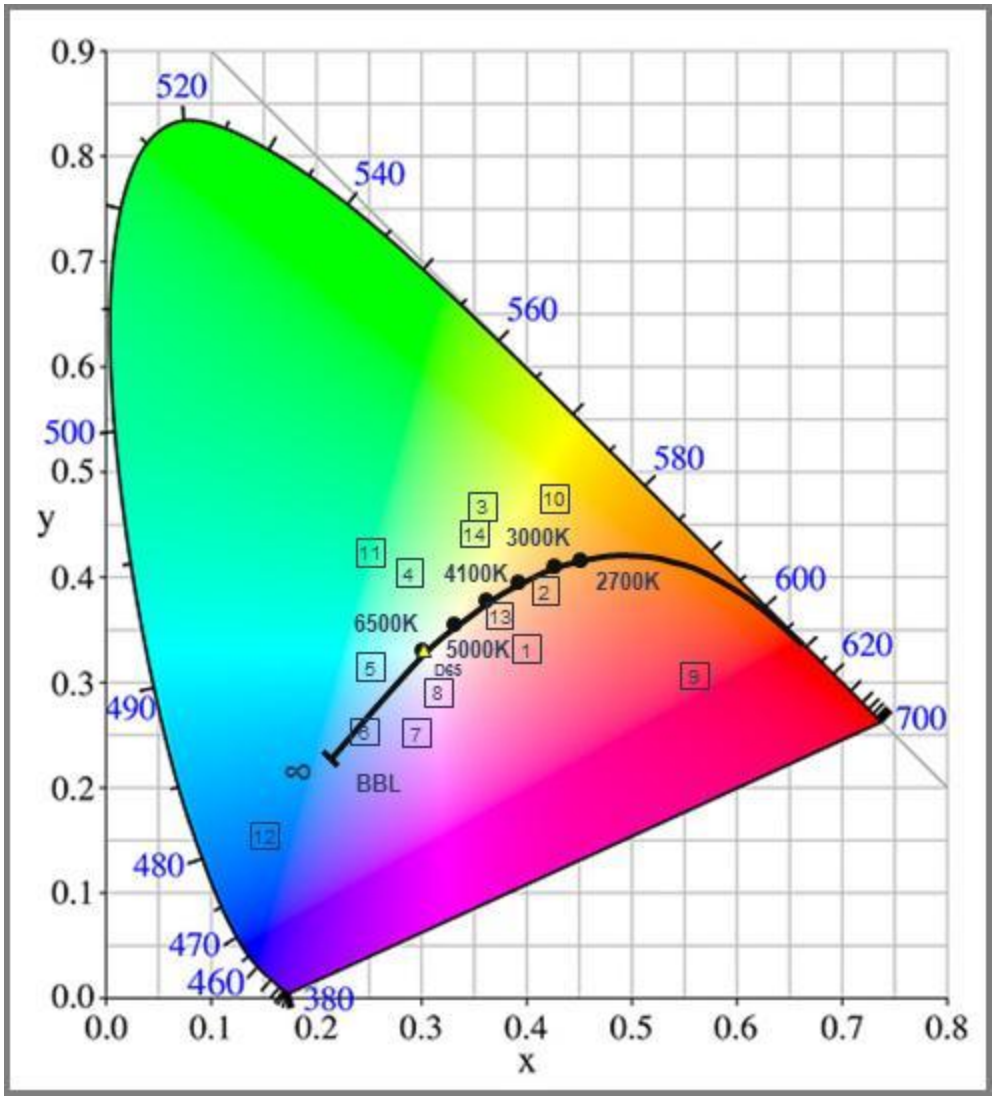
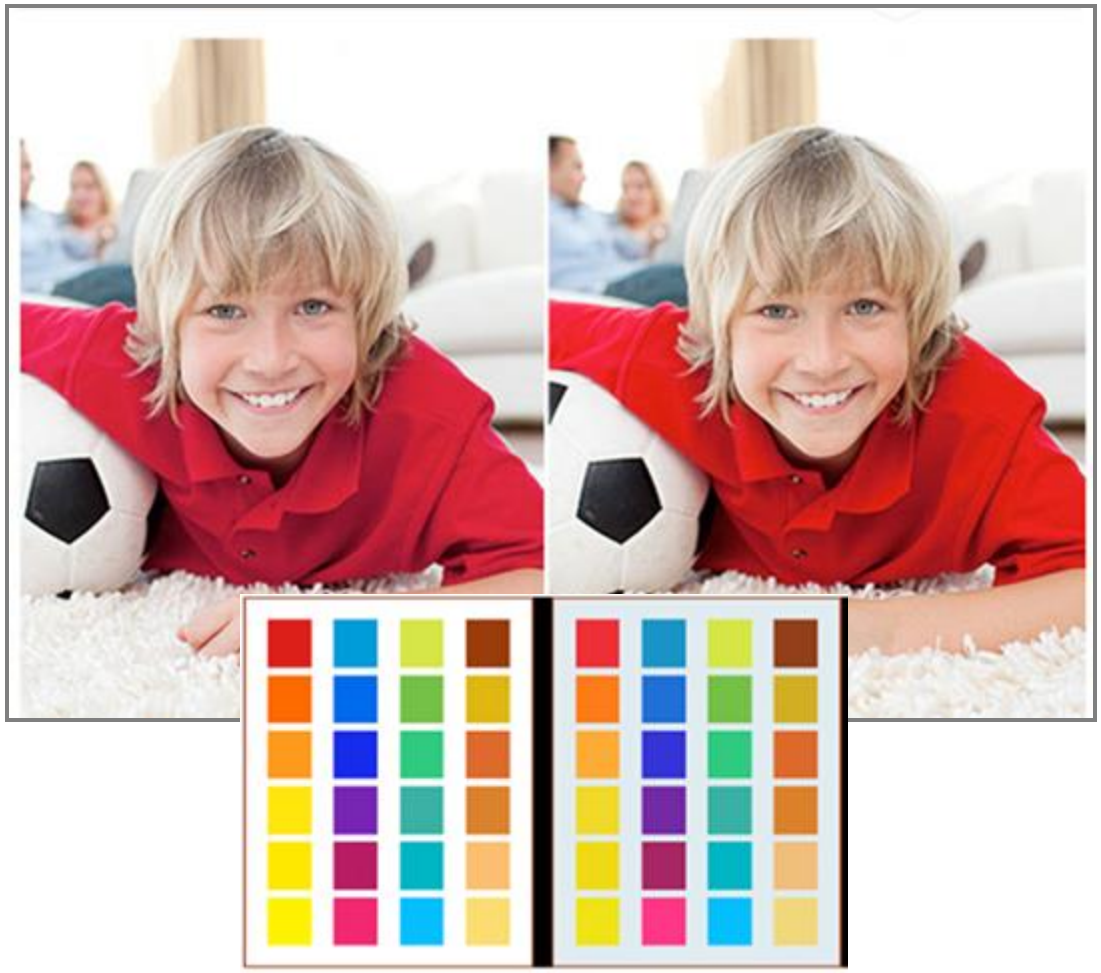
CRI Referenced to 14 Major Color Palettes



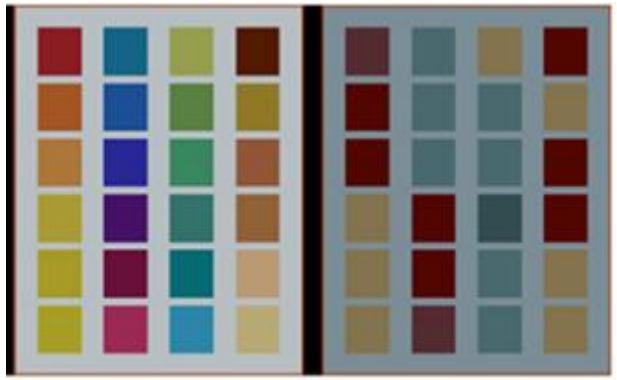
Some Stuff Looks Good; Some Stuff, Not-so-much…

CRI=85 CRI=78



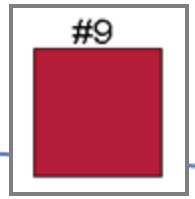
CRI = 85 CRI = 78

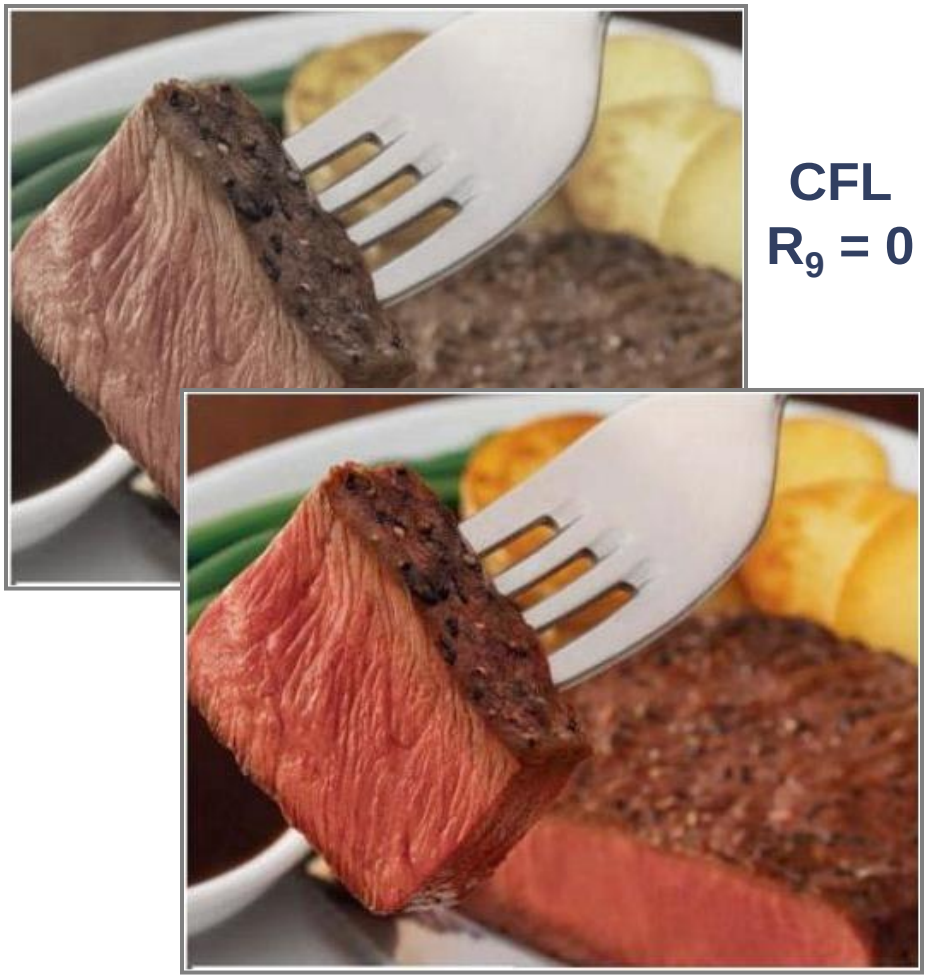
Na Vapor Lamp



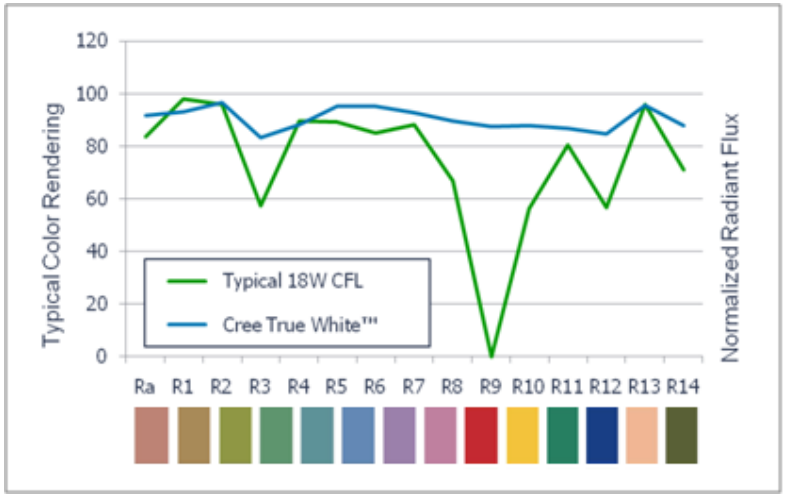
CRI = 65 CRI = 22

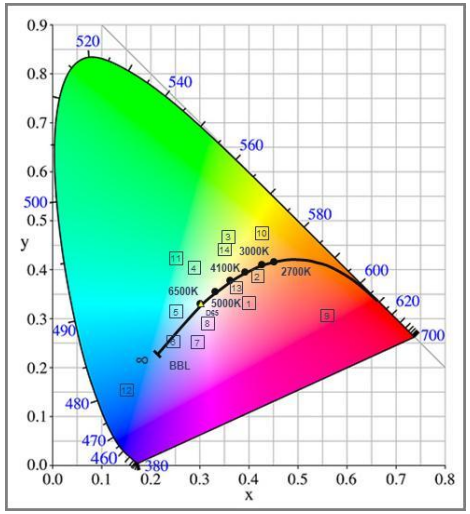
Why Your Customer Cares about #9





CFL
$R_9 = 0$





[It's What's For Dinner]

Cree TrueWhite™
$R_9 = 90$

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Figures of Merit for Color Quality Beyond CRI - Vividness

- "Color Quality" has been measured by CRI: "Fidelity"
  - color ***resemblance*** to the blackbody
- But color quality has a 2nd attribute: "Vividness"
  - color ***saturation*** relative to the blackbody

http://www.slideshare.net/TinaPrigge/dont-lose-color

Lower CRI

Higher CRI

- Right-hand side is clearly better: but is this fidelity, or is it saturation?
- In the past fidelity and vividness both increased with CRI, but SSL technology is changing
- New opportunity: more vivid light sources give customers a choice

Higher Vividness is Sometimes Preferred

NIST studies (Yoshi Ohno)

- For colorful objects, people prefer more vivid light sources than CRI predicts

CRI 94

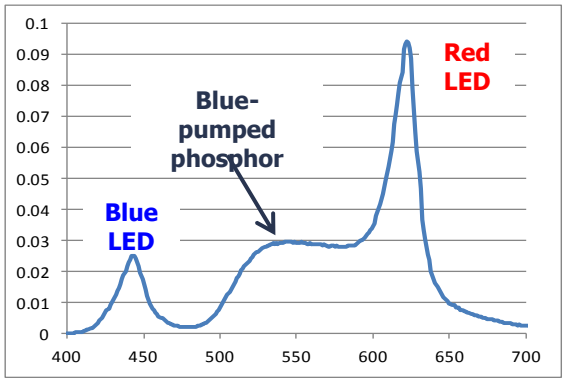
CRI 78

This looks better (for most people)

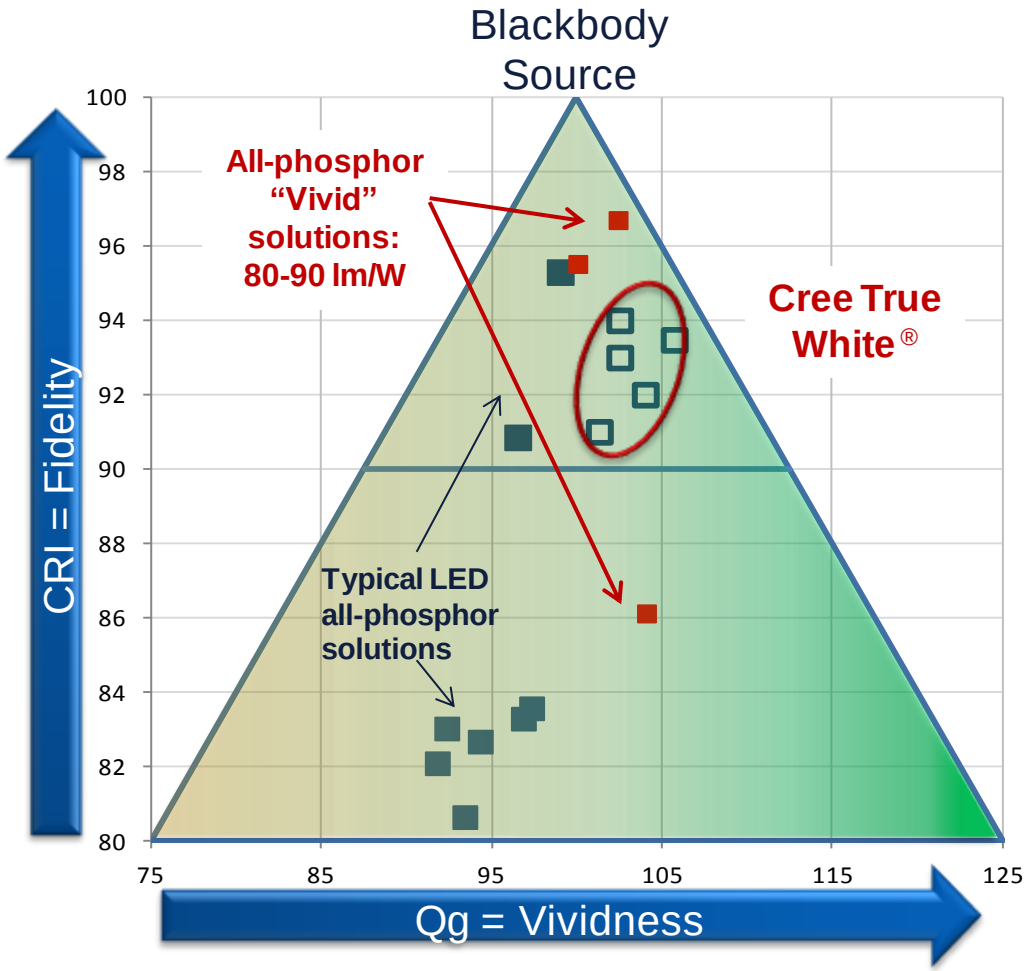
*Yoshi Ohno, "Latest Research and Standardization on Chromaticity & Color Quality of LED lighting," *SSL China*, Nov 2014

Color Quality Beyond CRI is Here Today

- True White® has higher vividness AND high fidelity:
  - >120 lm/W Product
  - 200 LPW R&D

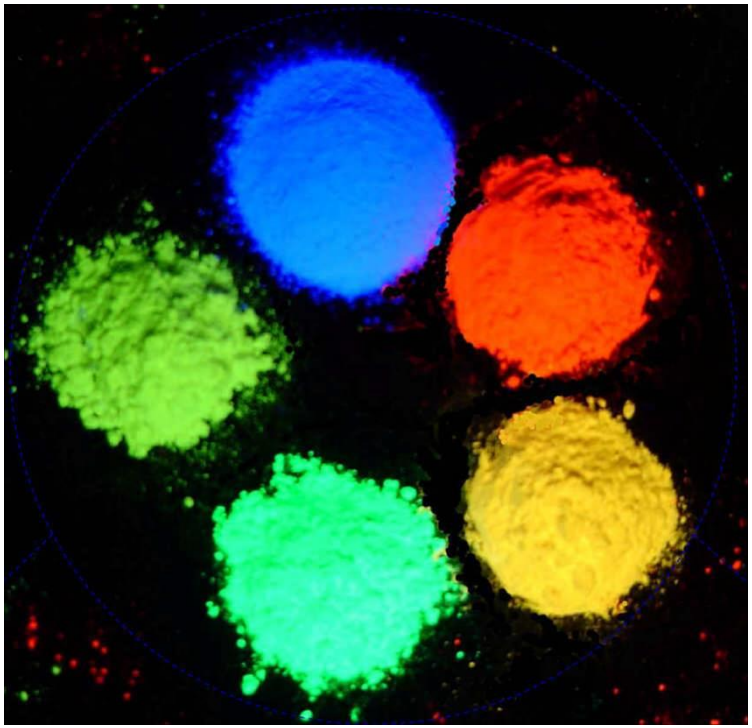


- Technology can be optimized still further



More Can Be Done

- Increase Vividness via narrow spectral components
  - Other LED colors
  - New Phosphors



- Need to open up our color quality definitions to capture higher vividness than in the past
  - Ex: 90 CRI rules could hold back color quality as vividness increases
  - Current NIST and IES Color Quality Task Force efforts are a good start

Figures of Merit For Lighting

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- **Lumens**
  - **Brightness of a light source**
- **Lumens/W**
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Real LED Levels of Performance (Current)

Just like traditional lamps, LEDs have losses beyond the boiler plate data sheet specs…

…but the source of losses are somewhat different:

- **Thermal (also a source of Lumen Depreciation)**
- **Optical (lenses, etc.)**
- **Driver (electrical losses in power conversion and dimming)**

For blue + phos

	6000K	4100K	3500K	2700K
Data Sheet LPW	200	180	160	140
Typical* Thermal Loss	10%	10%	10%	10%
Typical* Optical Loss	10%	10%	10%	10%
Typical* Driver Loss	15%	15%	15%	15%
Achievable* LPW	138	124	110	96
CRI	~75	~80	~82	~83

* Typical with average/good design practices

Note: Does Not include Cree's BSY + Red Technology

Projected LED Levels of Performance (2017)

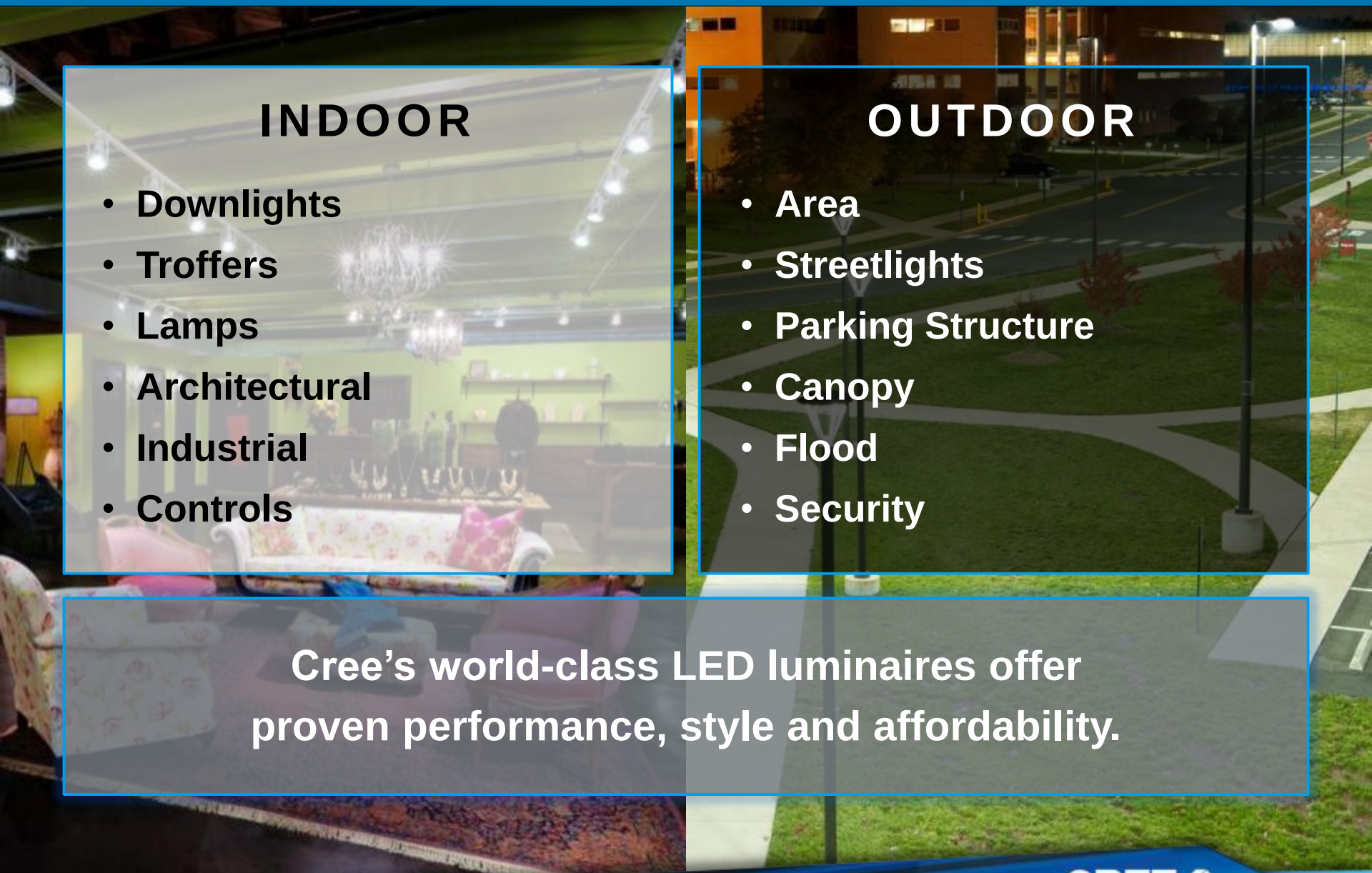
Up 25% over next 3 years

	6000K	4100K	3500K	2700K
Data Sheet LPW	250	225	200	175
Typical * Thermal Loss	5%	5%	5%	5%
Typical * Optical Loss	5%	5%	5%	5%
Typical * Driver Loss	8%	8%	8%	8%
Achievable * LPW	208	187	166	145
CRI	~75	~80	~82	~83

* State-of-the-art

- **LEDs will be the most efficient mainstream light source available**
  - **>185 delivered LPW roadway light possible (4100K)**
  - **Indoor fixtures >145 LPW (wall-plug)**

Commercial Application Solutions



INDOOR

- Downlights
- Troffers
- Lamps
- Architectural
- Industrial
- Controls

OUTDOOR

- Area
- Streetlights
- Parking Structure
- Canopy
- Flood
- Security

Cree's world-class LED luminaires offer proven performance, style and affordability.

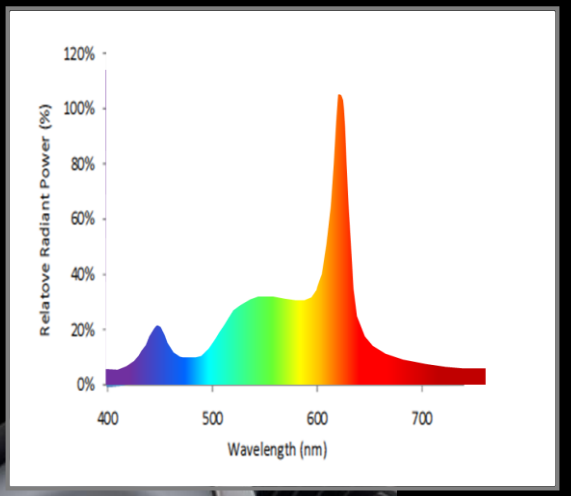
CREE

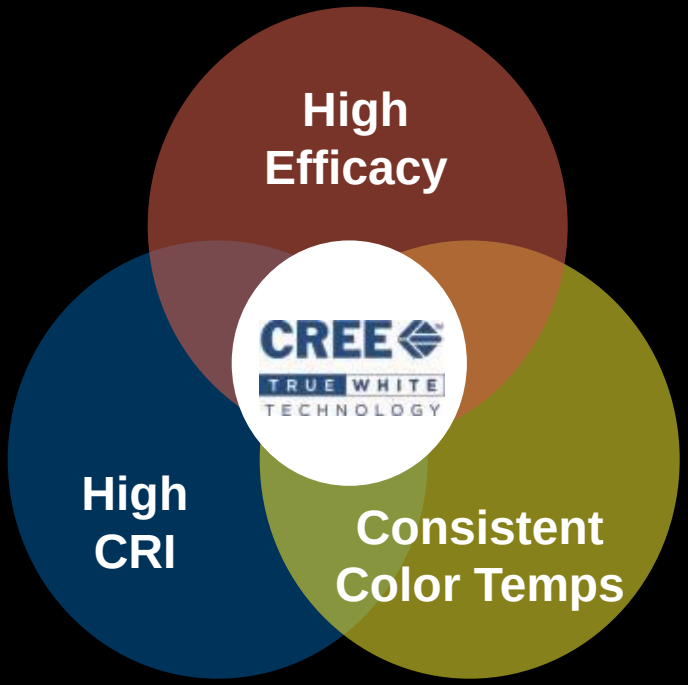
INDOOR

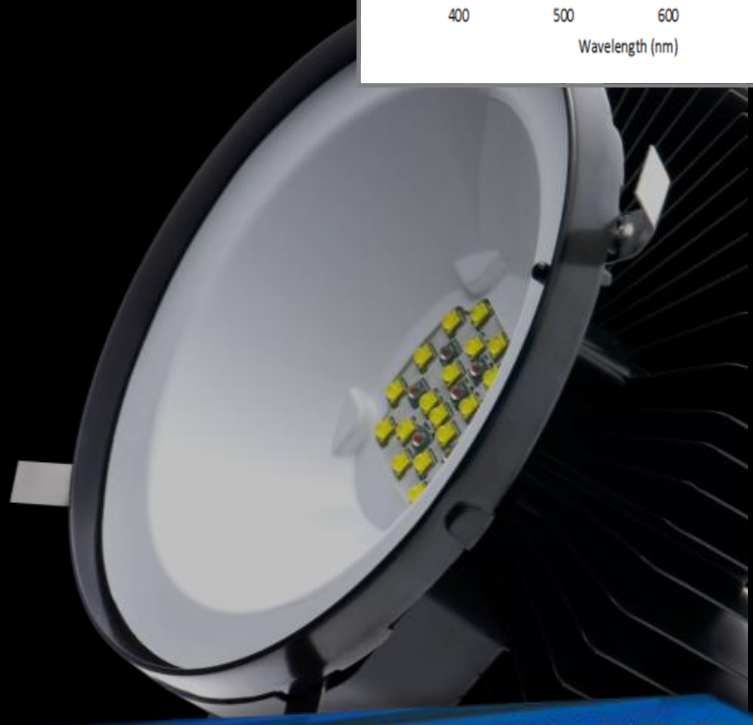
Cree TrueWhite® Technology Advantage

Color Mixing & Tuning

Patented **mixing of LEDs** delivers an improved visual environment using significantly less energy than traditional lighting technologies







Lamp Applications

Bentonville, AK

PAR38

MR16

CREE

CS18

New Leaf Market - Tallahassee, FL (2012)

BEFORE – 6-LAMP T8

Quantity: 34
Total Watts: 6,120

Payback Just Over
8 Months

Total Lifetime Savings: $28,155 (50K Hrs)

Improved Vertical Illumination and Color Quality

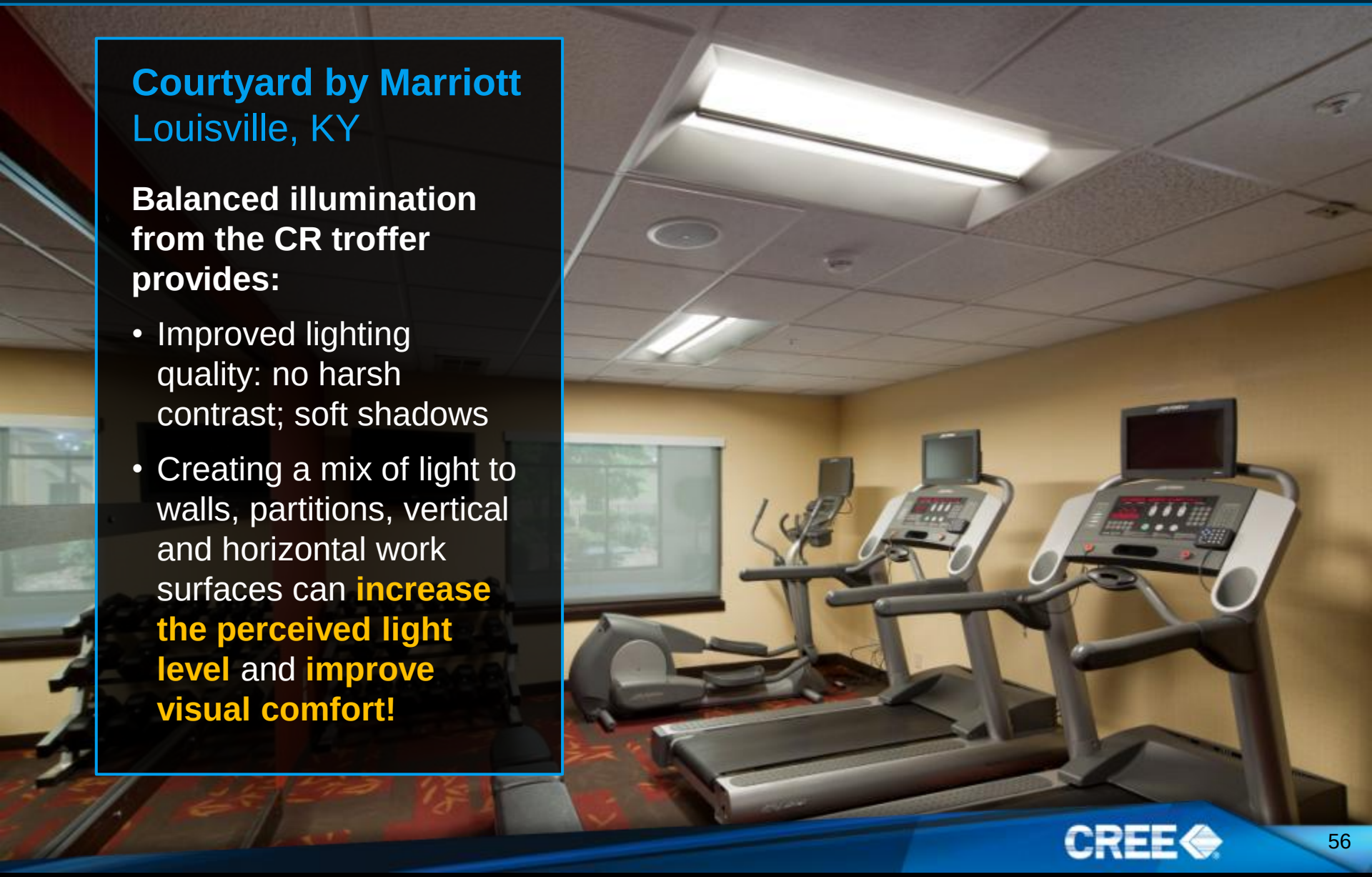
AFTER – CS18™ LED

Quantity: 38
Total watts: 2,660

56 % LESS

CREE

2 x 4 Troffers



Courtyard by Marriott
Louisville, KY

Balanced illumination from the CR troffer provides:

- Improved lighting quality: no harsh contrast; soft shadows
- Creating a mix of light to walls, partitions, vertical and horizontal work surfaces can **increase the perceived light level** and **improve visual comfort!**

ZR HE – 150 LPW 90 CRI 4000 Lumen Fixture !!!

- Cree TrueWhite® Technology
- **Delivered Light Output:** 3200, 4000 lumens
- **Input Power:** 21 to 44 watts
- **LPW:** 90-150
- **CRI:** 90
- **CCT:** 3500K, 4000K
- **Input Voltage:** 120-277 VAC
- **Lifetime:** Designed to last up to 75,000 hours (standard) and 100,000 hours (HE)
- 10-year limited warranty
- **Mounting:** Recessed

Applications

- Petroleum & Convenience Lighting
- Airport Lighting
- Auto Dealership Lighting
- Corporate Campus Lighting
- Education Facilities Lighting
- Government Facilities Lighting
- Healthcare Facilities Lighting
- Municipal Lighting
- Recreation & Public Venue Lighting
- Restaurant & Hotel Lighting
- Retail & Grocery Lighting

OUTDOOR

The Prairie School - Racine, WI

2007

Cree Edge™ Area Square

Edgewater Marketplace - Edgewater, CO

BEFORE - HID

19.1kW

AFTER - LED

6.5kW

CREE

LEDway® Street Light

Smithtown, NY (2010)

$225,000

in Annual Energy and Maintenance Savings!

(1,100 luminaires)

52% LESS

BEFORE - HPS

400W

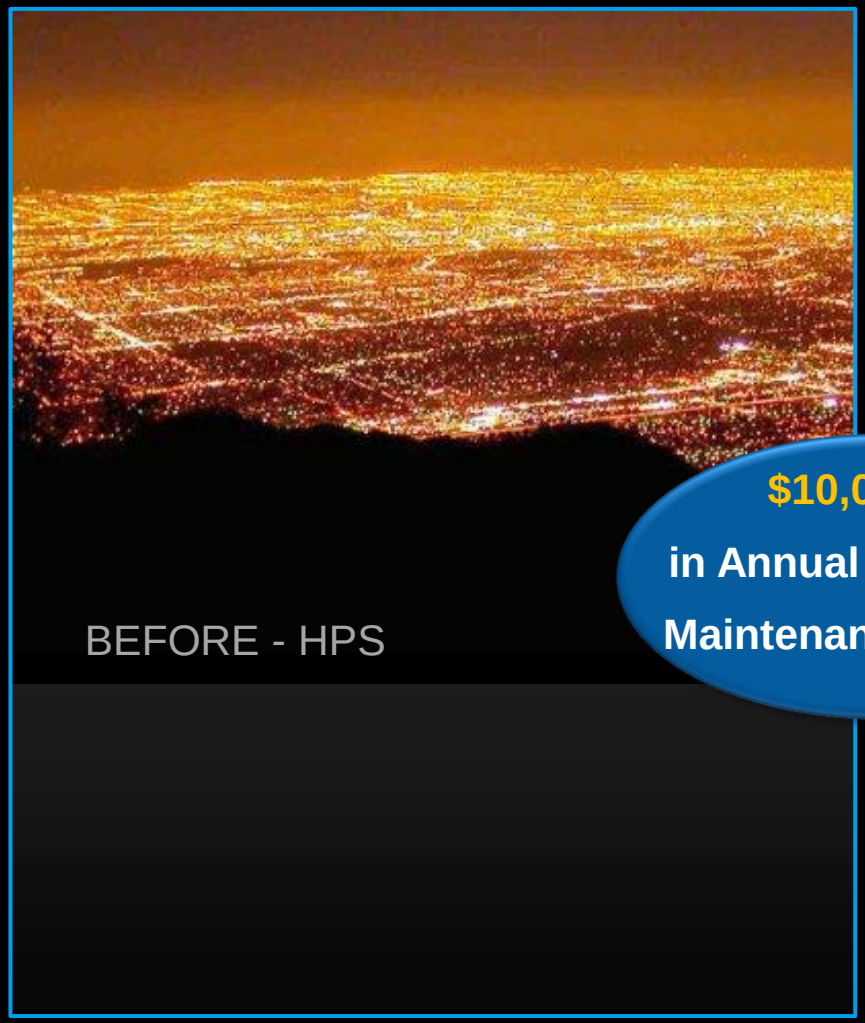
AFTER - LED

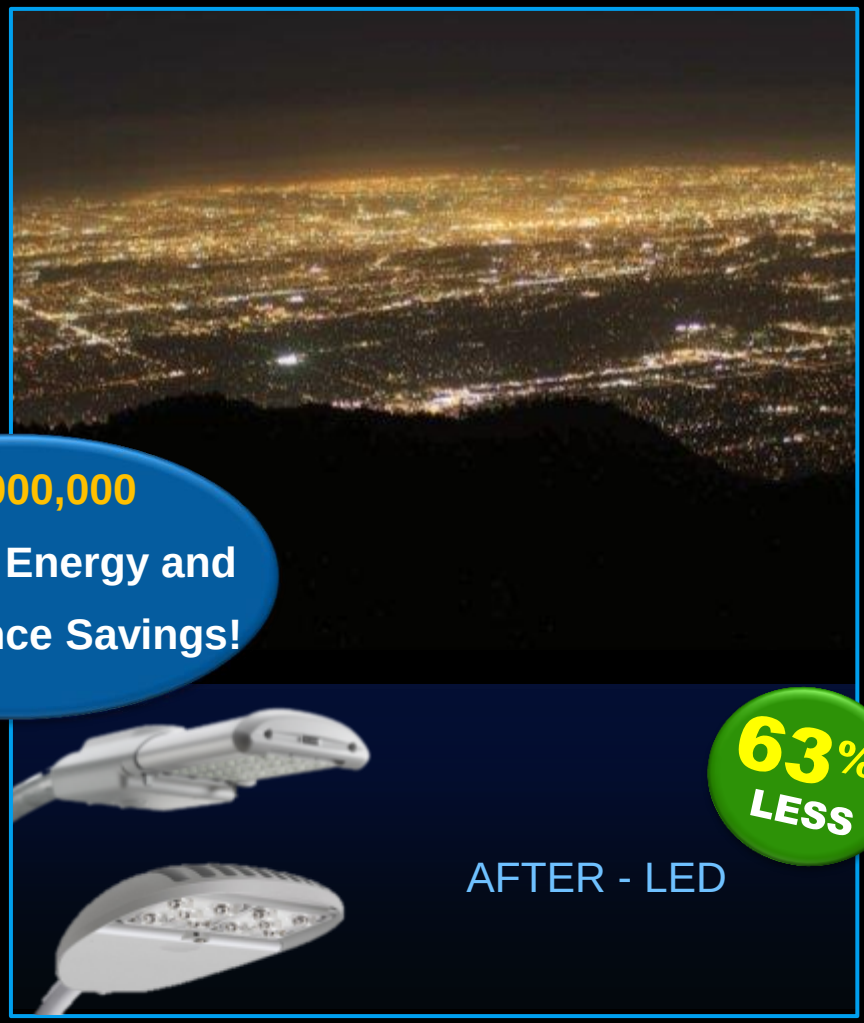
150 & 200W

CREE

LEDway® and XSP Street Light

Los Angeles, CA (2008-2012)





$10,000,000
in Annual Energy and Maintenance Savings!

CREE

Traditional Post-Top LED Upgrade Kit

State Street
Racine, WI

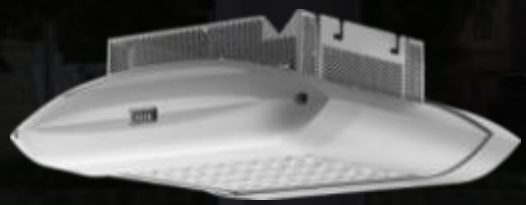
LED Upgrade Kits for:

- Holophane®
  - Esplanade® Teardrop
  - Granville Acorn
  - Washington Post-Lite® Acorn
- King® Luminaire Washington Acorn
- Lumec® New Westminster Globe

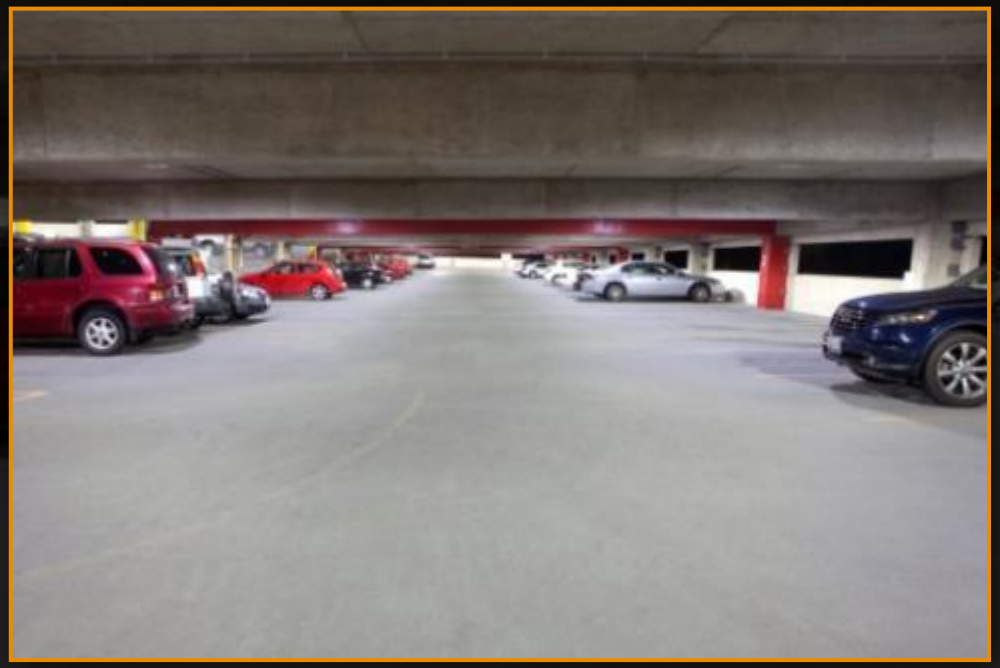
Cree Edge™ Surface Mount Canopy

Richlands Station
Queensland, Aus.

- Modern look
- Excellent vertical light for pedestrians
- One-for-one replacement is a popular option
- Wide range of optics and lumen outputs



304 Series™ Parking Structure



Advocate Brommen
Normal, IL

Typical installation using no controls

- 2.4 year payback
- $405K lifetime savings*

Typical installation using occupancy sensors

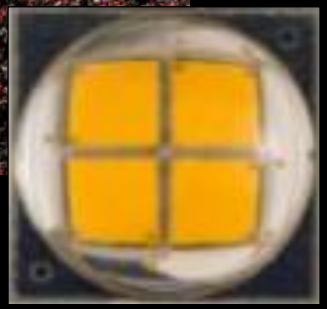
- 2.3 year payback
- $516K lifetime savings*

Cree CPY250™ Surface Mount Canopy

Raleigh, NC

Super Bowl 2015

Ephesus Lighting
Powered by Cree® LEDs



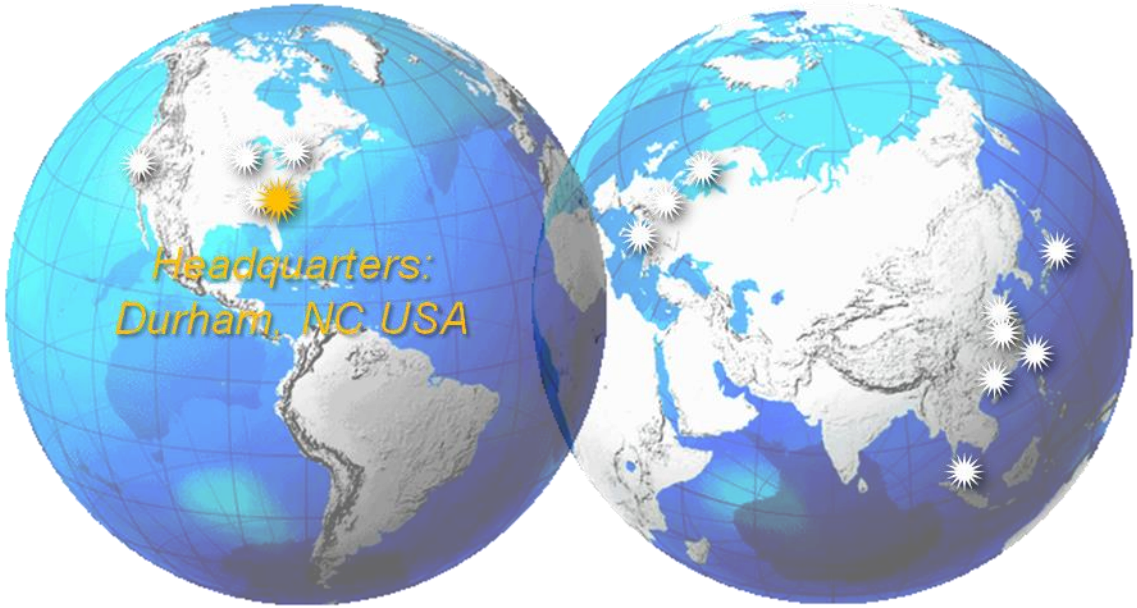
Outline

- Fundamental Approach
- LED Milestones
- LED Chips and Components
- The light bulb: Edison to LEDs
- LED General Lighting
- **End Results: Jobs!**

Cree Company Overview

GLOBAL SCALE

- 28 global locations
- 7,100 employees



CREE FACTS

Fiscal 2014 Revenues	*$1.6B*
Fiscal 2014 Op. Cash Flow	*$319M*
June 2014 Cash & Investments	*>$1.2B*
Long-term Debt	*0*

NASDAQ
CREE

A Global Company

R&D

- Durham, NC
- Research Triangle, NC
- Racine, WI
- Santa Barbara, CA
- Florence, Italy
- Hong Kong

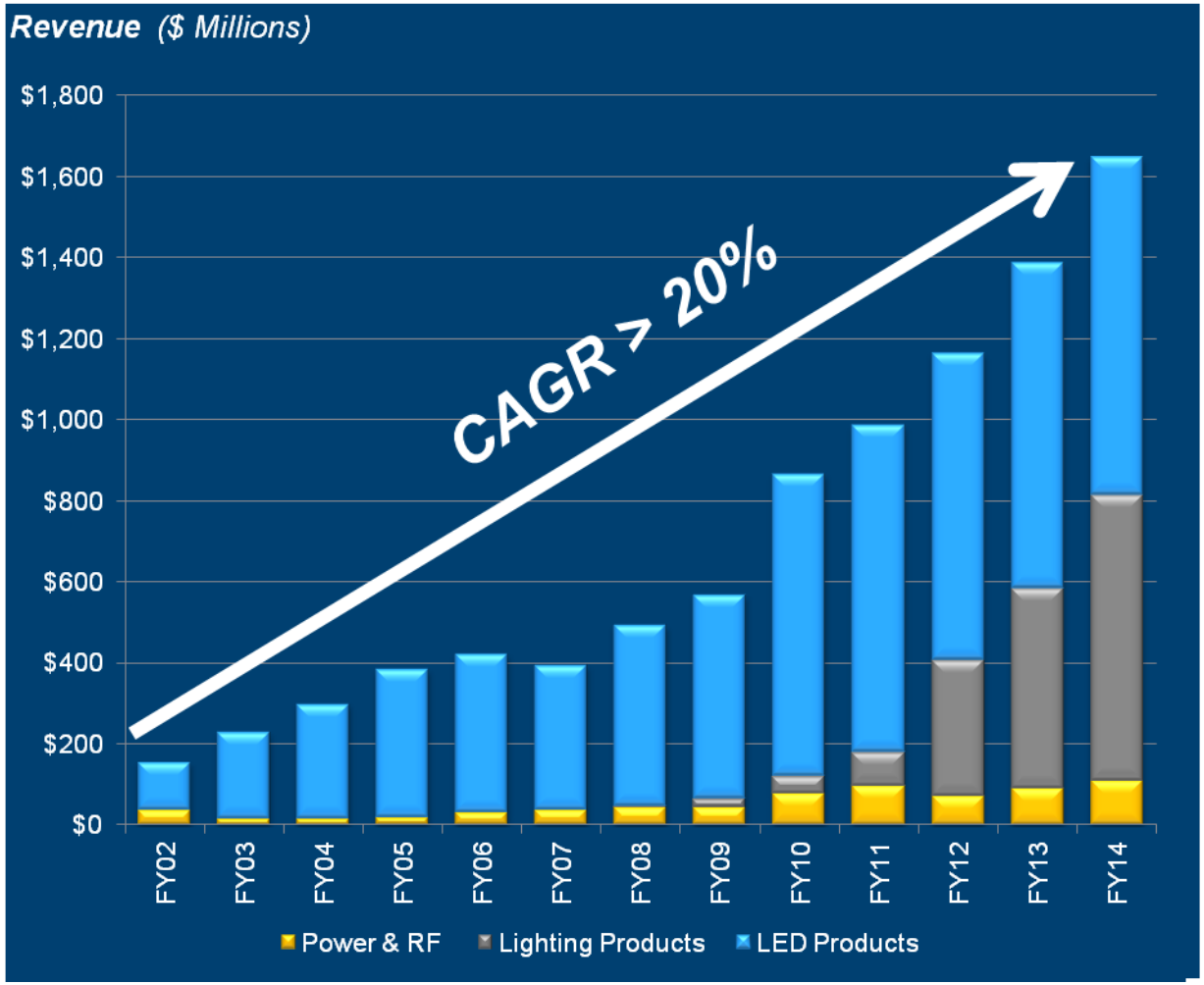
Manufacturing & Distribution

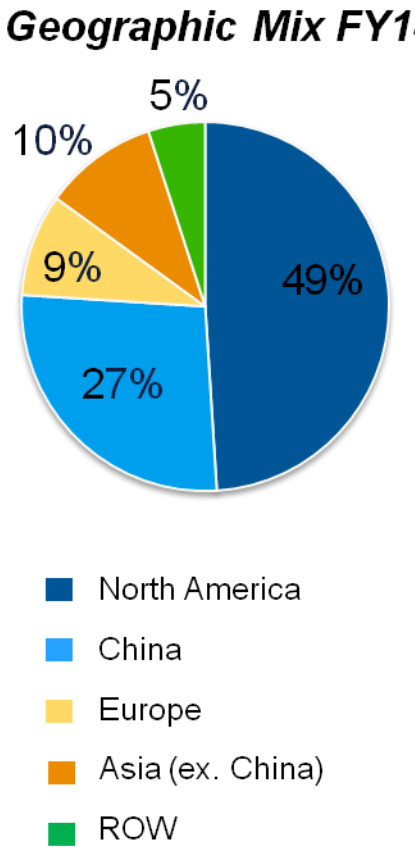
- North Carolina, USA
- Wisconsin, USA
- Italy
- China
- Canada
- UAE
- Australia

Sales

- USA
- Canada
- Mexico
- Germany
- France
- Italy
- Turkey
- UK
- China
- Singapore
- Japan
- Taiwan
- South Korea
- Russia
- UAE
- India
- Africa
- Chile
- Guatemala
- Australia
- New Zealand
- Panama
- Columbia
- Brazil

Track Record of Growth





Cree and SSL are Making a Difference

- Leader in Creating and Growing an LED Lighting Industry
- Thousands of good-pay jobs created
- Thank you DOE for your support along the way