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# LEDs: Ready for Liftoff?

Chris Calwell, Senior Research Fellow

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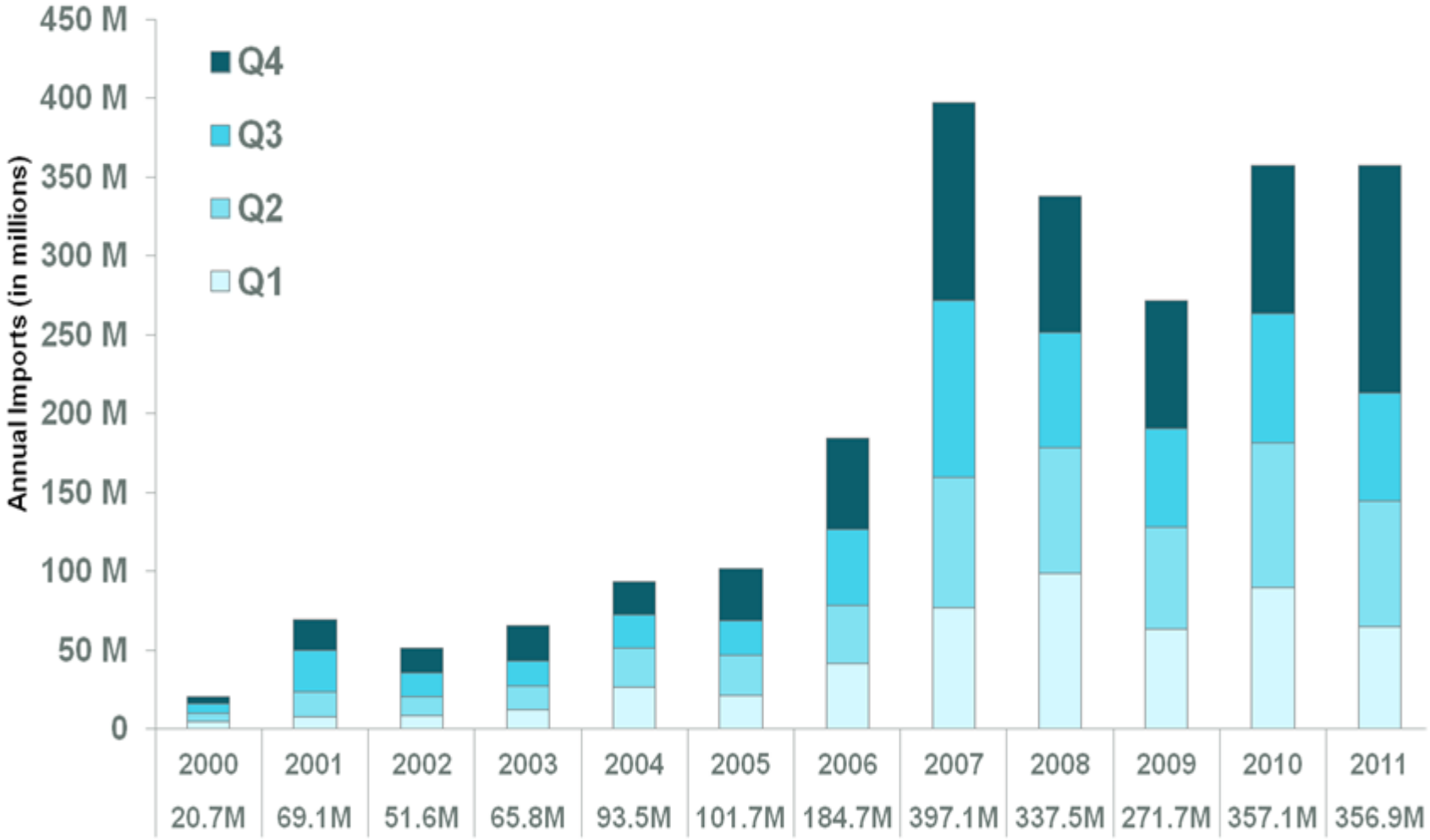
# Historical Approach to Utility Residential Lighting Programs

- Stated goal: "a CFL in every socket"
- Premise: CFLs are the ideal light source, cheap, long-lasting, highly efficient. If we just promote them long enough, eventually everybody will use them everywhere!
- Reality: CFLs are a pretty good light source for most applications for *some* people, and for some applications for *most* people. CFLs are now cheaper than the equivalent number of incandescents they replace, *without* considering energy savings. So rebates may not be decisive in getting the unpersuaded to give them a try. They're no longer the newest and most high tech kid on the block for early adopters – LEDs have passed them up.
- Lesson: People don't buy light bulbs primarily to save energy; they buy them to provide light. Need to ensure, first and foremost, that the products we are promoting provide outstanding light.

# US Imports of CFLs over Time – 2007 Was Peak Year and Socket Share Flattening at about 20-25%




Source: USA Trade Online® - Foreign Trade Division of the U.S. Census Bureau

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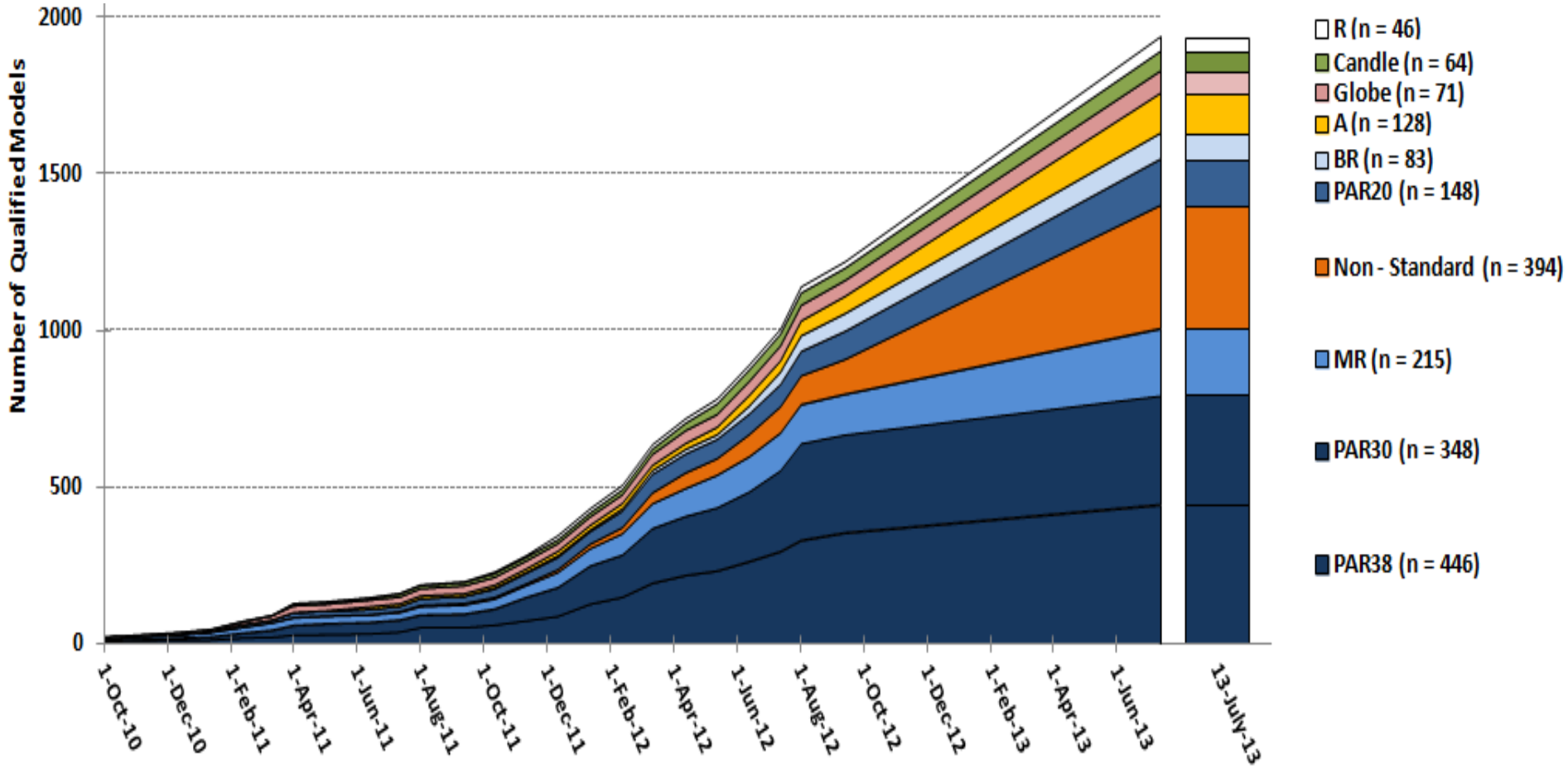
# Early LEDs: Possibly Even Worse than Early CFLs!

- Not bright enough
- Bulky
- Heavy
- Ghastly color
- Not dimmable
- Looked even weirder than early CFLs
- Cost even more than early CFLs ($60-$80 vs. $20-$30)
- Light dispersion not remotely omnidirectional

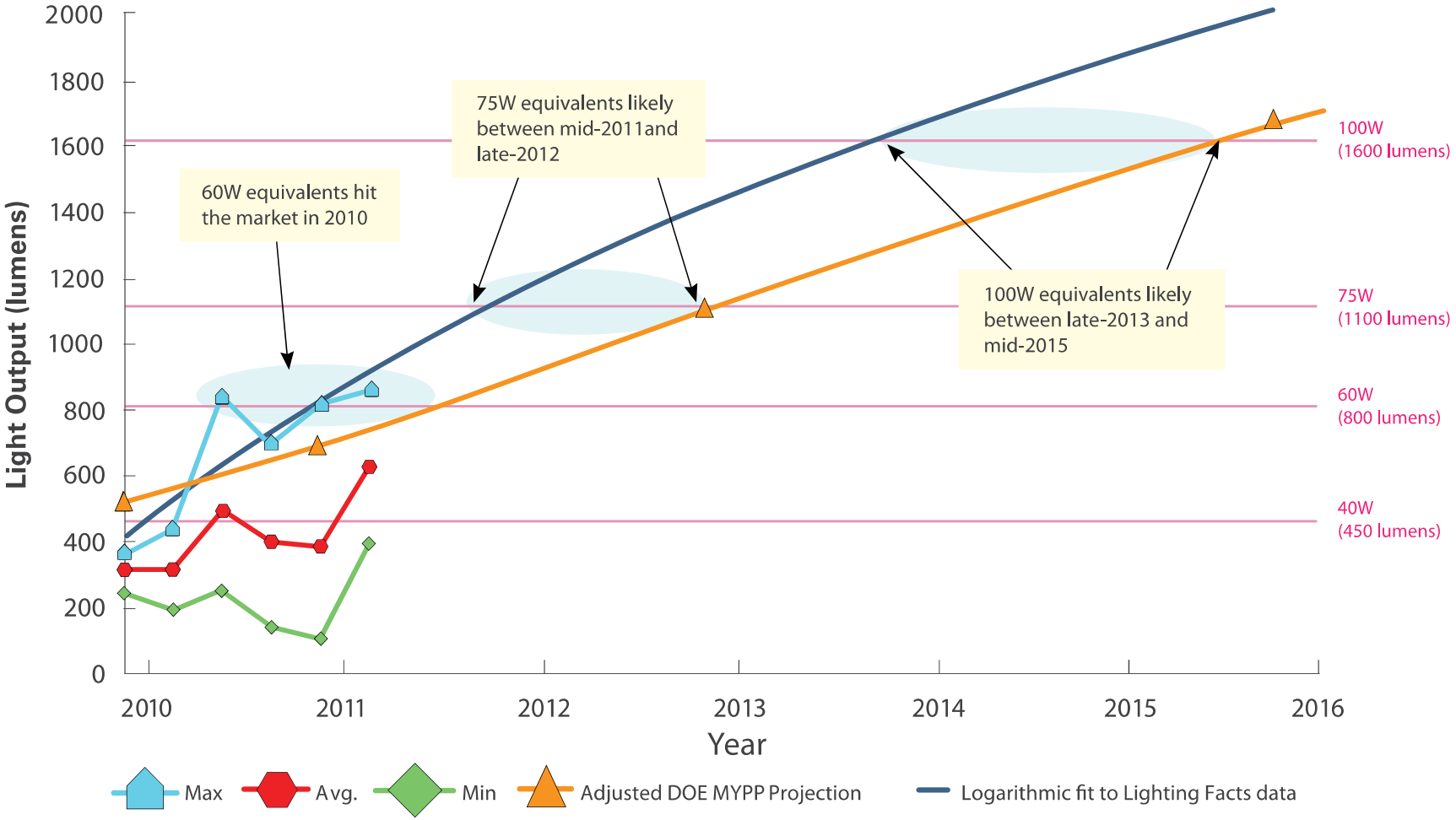
But early LEDs did show promise in a few key areas that kept development going:

- Very long-lived
- Light output, efficiency and cost all improved much faster than they did with CFLs
- Inherently directional (made them a natural for reflector lamp applications where CFLs struggle)

# Growth in ENERGY STAR Labeled LED Models

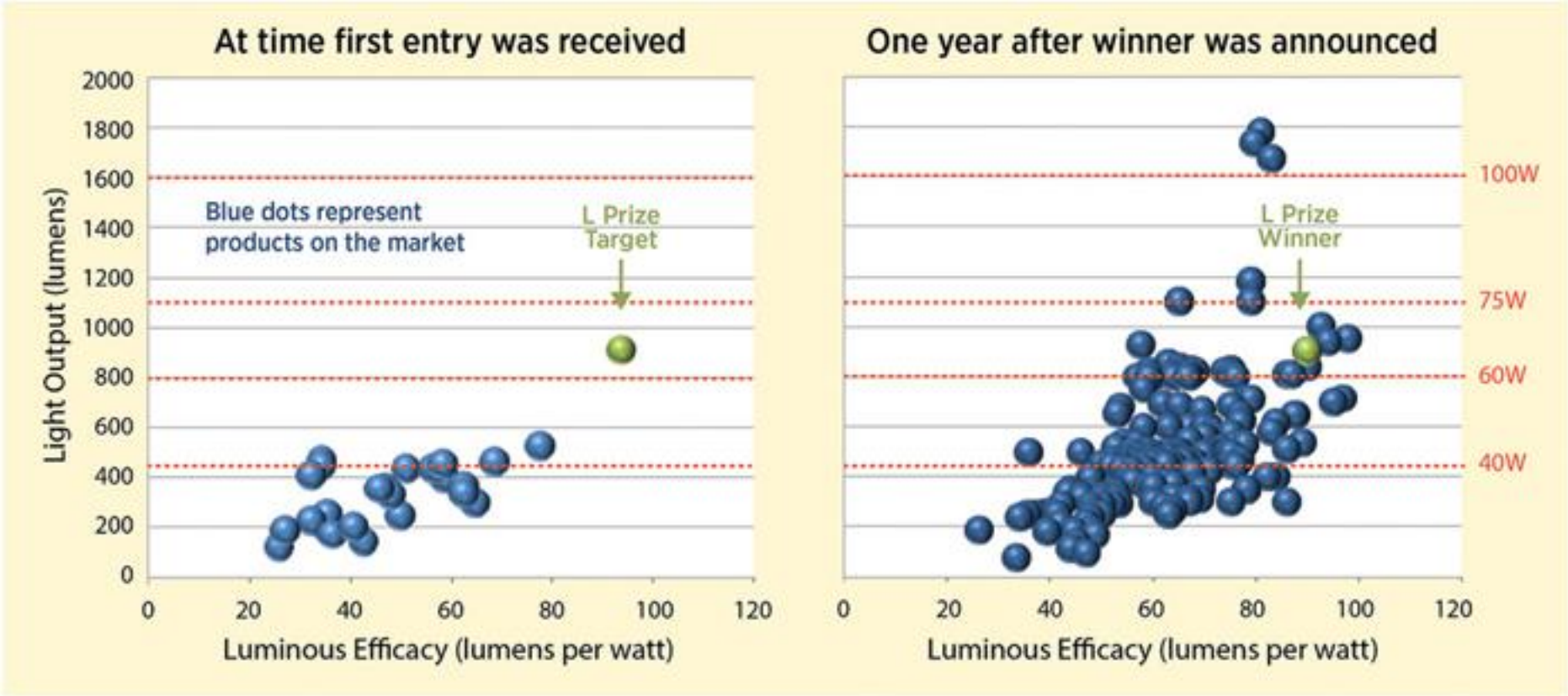


# LED A-Lamps Getting Brighter and More Efficient




Source: DOE Lighting Facts® Program. Product Snapshot: LED Replacement Lamps, April 2011

# Omnidirectional LED Progress Over Time




Source: US Department of Energy *e-Update*, May 2013

# Plusses & Minuses of LEDs as the Preferred Efficient Residential Light Source

- Efficiencies now often 60-85 lm/W (relative to ENERGY STAR minimum of 45 lm/W) and heading higher
- Products routinely dimmable
- Color can be easily tuned to different colors
- Better optics solving the problem of uniform light distribution
- Fundamental semiconductor efficiency gains have cut the number of LED sources needed, reducing associated costs & size for heat sinks & drivers
- LEDs becoming less weird-looking, but still need to make further progress
- LED lamp sizes and weights in the 1600 lumens or greater category are still too high
- Prices for the brightest LEDs are also still off the charts for most buyers - $50 to $80 per bulb, so still not as *cost effective* as LEDs
- Rate of improvement is so fast that waiting 6 months always seems worth it – newer products will always be cheaper, brighter, smaller, and better

# Bright, Small, Efficient or Affordable: Hard to Optimize for Everything

# Beware the “Snow Cones” -- Special Optics Needed to Disperse LED Light Evenly in All Directions


Meets ENERGY STAR
Omnidirectional requirements

Non-Standard LED A-Lamp

Omnidirectional LED A-Lamps


# Voluntary California Quality LED Lamp Specification Aims to Improve Lamp Performance with a Focus on Six Attributes

- Color temperature
- Color consistency
- Color rendering index
- Dimmability
- Lifetime
- Light distribution

CREE®

Lighting | LED Components & Modules | LED Chips & Materials | Power | RF

# Cree Sets New Standard for LED Bulbs

**New Cree TW Series LED Bulb**
**First to Meet California Energy Commission Quality Lighting Specification.**

Learn more


**Recent News** | Cree Introduces New High-Density Class of XLamp CXA LED Arrays

More News

**Cree is a market-leading innovator of** lighting products, LED components, and semiconductor products for power and radio-frequency (RF) applications.

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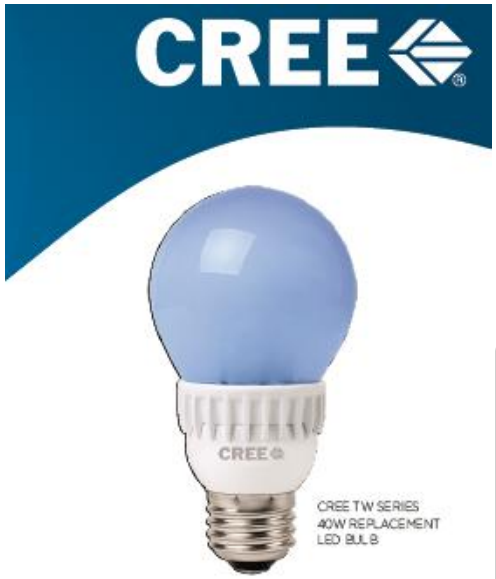
# Do we want consumers to pay 54% more for 30% lower efficiency?

## 84 lm/W, CRI=80, $12.97


**Lighting Facts**
Per Bulb

| | |
|---|---|
| **Brightness** | **800 lumens** |
| **Estimated Yearly Energy Cost** Based on 3 hrs/day, 11¢/kWh. Cost depends on rates and use | **$1.14** |
| **Life** Based on 3 hrs/day | **22.8 years** |
| **Light Appearance** Warm — Cool, 2700 K | |
| **Energy Used** | **9.5 watts** |

## 59 lm/W, CRI=93, $19.97




### Why is it blue?

The rare earth element neodymium is added to the glass of our Cree TW Series LED bulbs to augment the LED light. This creates a "spectral notch," allowing the LED light passing through the glass to show colors that are true and natural.

**Lighting Facts**
Per Bulb

| | |
|---|---|
| **Brightness** | **800 lumens** |
| **Estimated Yearly Energy Cost** Based on 3 hrs/day, 11¢/kWh. Cost depends on rates and use | **$1.63** |
| **Life** Based on 3 hrs/day | **22.8 years** |
| **Light Appearance** Warm — Cool, 2700 K | |
| **Energy Used** | **13.5 watts** |

# “Never Confuse What Can Be Counted with What Counts”

- Tendency with product specifications to simply increase the qualification numbers over time as more and more products are receiving the ENERGY STAR label.
- Makes the qualification process more selective, but doesn’t necessarily lead to better outcomes if the original test procedures, efficiency metrics, or performance metrics aren’t measuring the right things.
- Try this test at home or in your office:  put two different LEDs with the same color temperature and light output into adjacent table lamps.  One should have a CRI of about 82-84 (typical of most ENERGY STAR models today) and the other should have a CRI of more than 90.
- Take a look at the light each casts on the wall and what shines through the shade. Hold your hand or a color photograph underneath each shade and study the colors carefully?  Does one look superior to the other?  Can you even tell the difference?
- In the informal tests we’ve done in our lab so far, subjects couldn’t consistently tell the 80+ CRI lamps aparts from the 90+ CRI lamps, let alone express a preference that would correlate to a willingness to pay more for the 90+ lamp.
- A perfect score on CRI doesn’t really tell you how a lamp will behave with the much wider range of colors, shades and subtle hues we all encounter in our homes.

# Color Temperature and Color Rendering Index capture only part of what it means for a bulb to provide attractive light

# Why Performance Matters – The Same Reference Color Swatches Lit by Two Different ENERGY STAR LED Bulbs

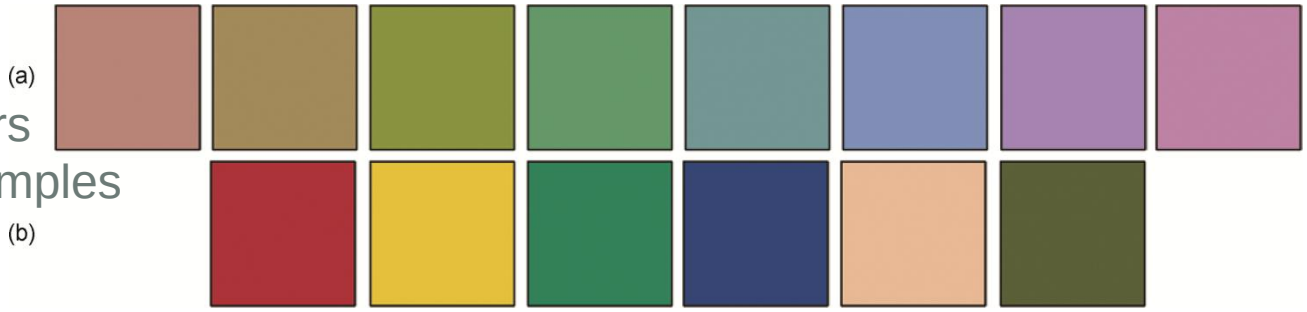
# Color Rendering Index (CRI) vs Color Quality Scale (CQS)

- Pastels, not saturated colors
- Simple average masks deviations

CRI

- Includes saturated colors
- RMS of 14 reflective samples

CQS




12-104
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12-67

# Asking the Question "What Makes an Ideal Bulb?" in a Different Way

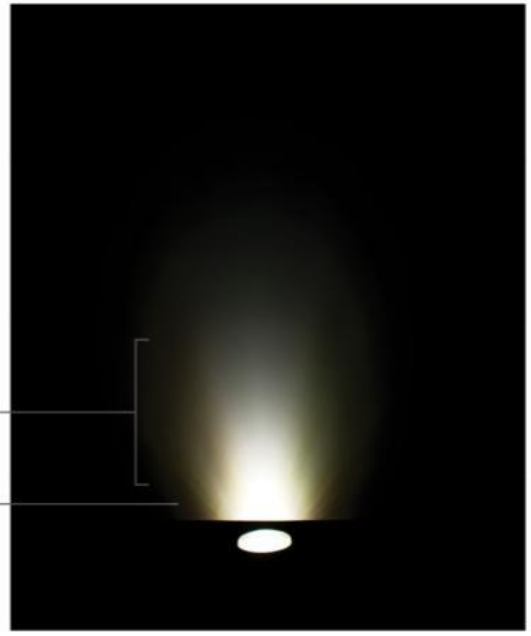
- No light bulb is perfect; each represents a mix of imperfect tradeoffs
- However, we can assign weightings to the attributes we want in a lamp and see which ones consistently deliver the highest score.
- In our LED reflector lamp work for IEE and TopTen USA, we found four key qualities were the hallmark of the best lamps:
  - Higher measured efficiency than required by ENERGY STAR
  - Lower than average lifetime cost of light and payback period (low incremental cost relative to their expected lifetime energy savings)
  - Better performance than average in the laboratory on a range of enhanced color, dimming, and technical attributes
  - And, most importantly, higher than average performance on human factors testing – perceived uniformity and natural appearance of the light itself, as judged in multiple paired comparisons by a panel of human subjects

Greatest breakthrough of this research was recognizing that subjective aspects of lighting matter quite a bit to the people who are being asked to pay $15, $25, or even $50 for something whose primary purpose in the home is aesthetic.

## Preferred

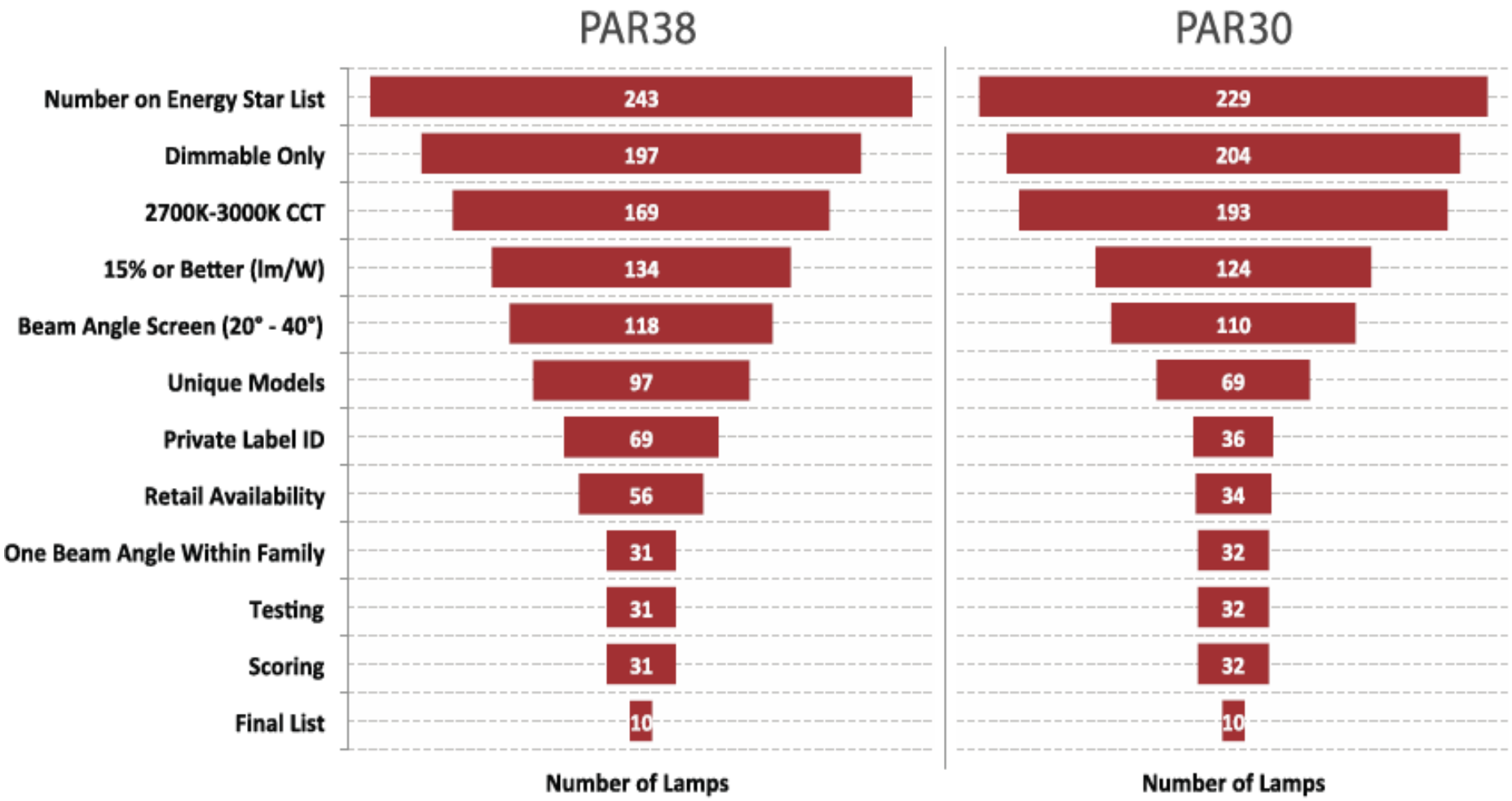
## Not Preferred

The human eye is very good at distinguishing “good” light from “bad” light

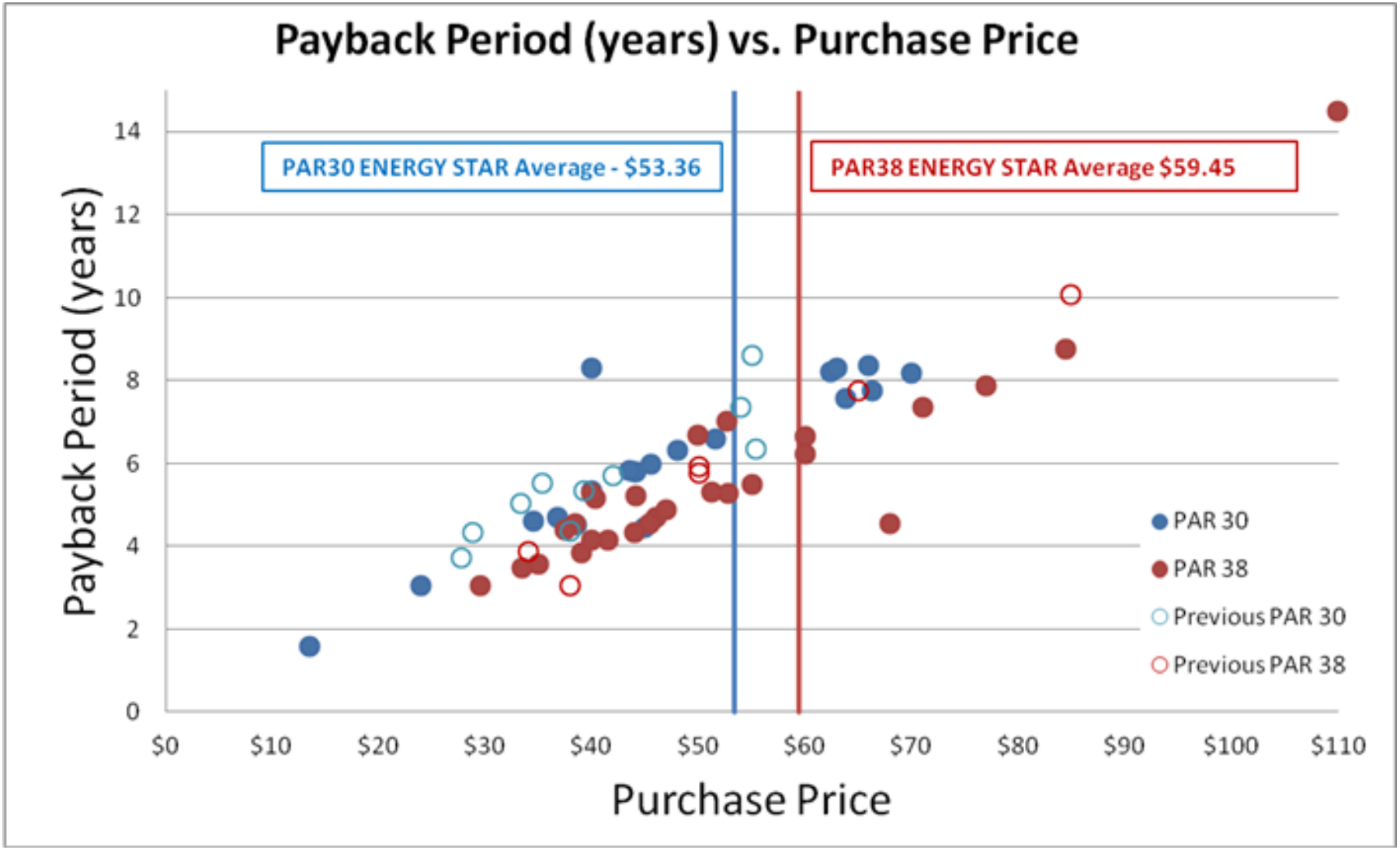


Beam patterns differ hugely from each other

# Selecting the Top Ten LED Reflectors – the Winnowing Process



# LED Downlight Data from our IEE/TopTen Project



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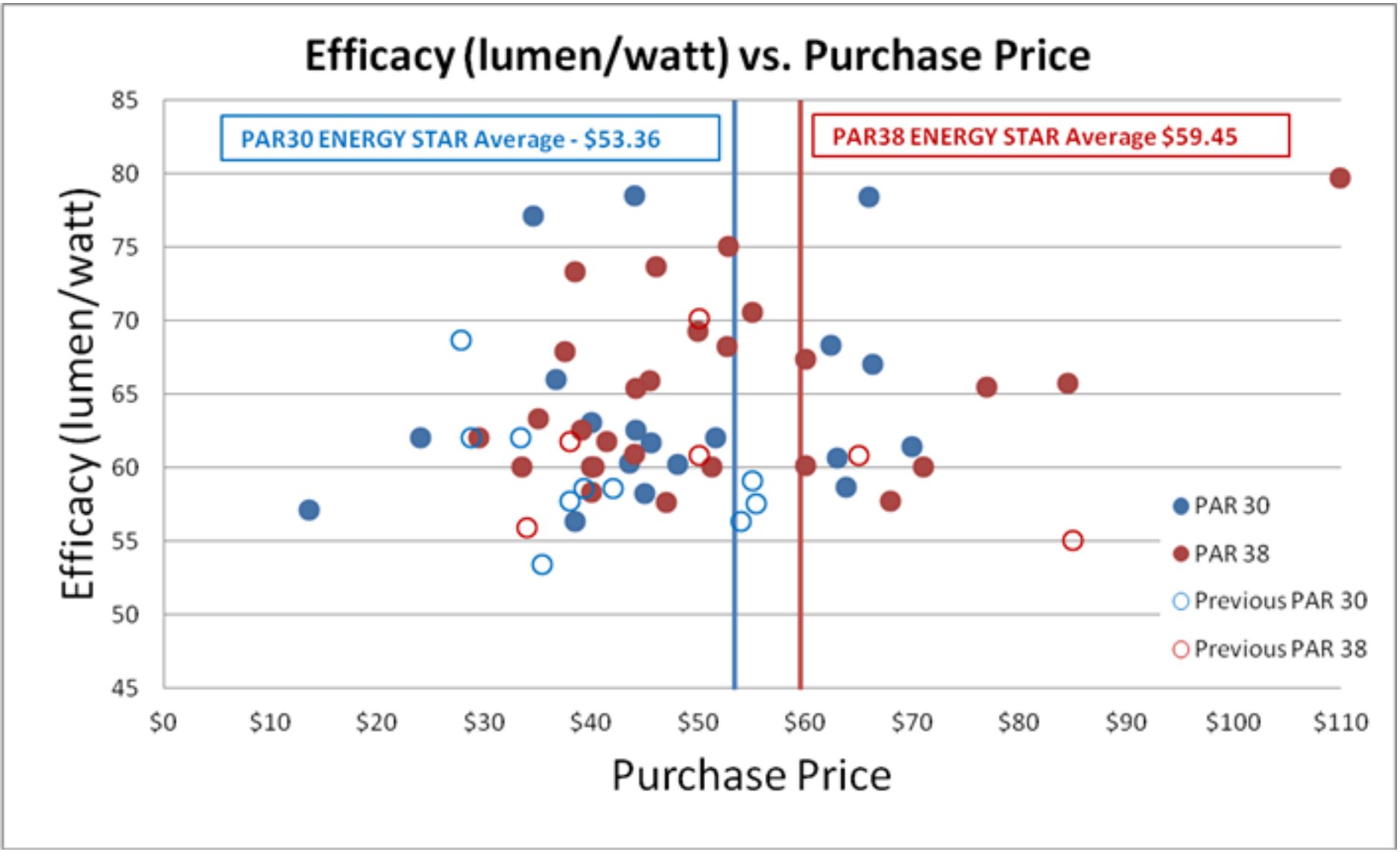


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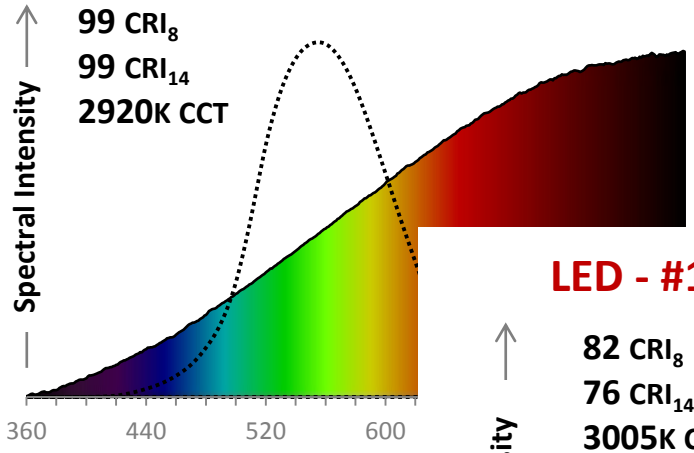
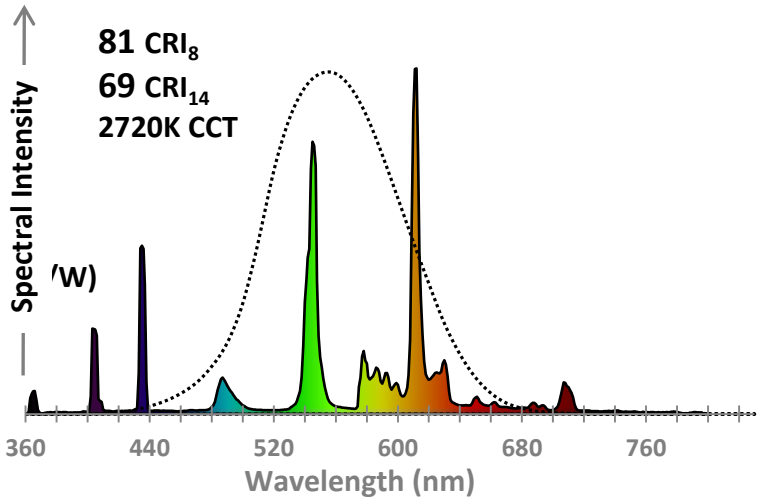
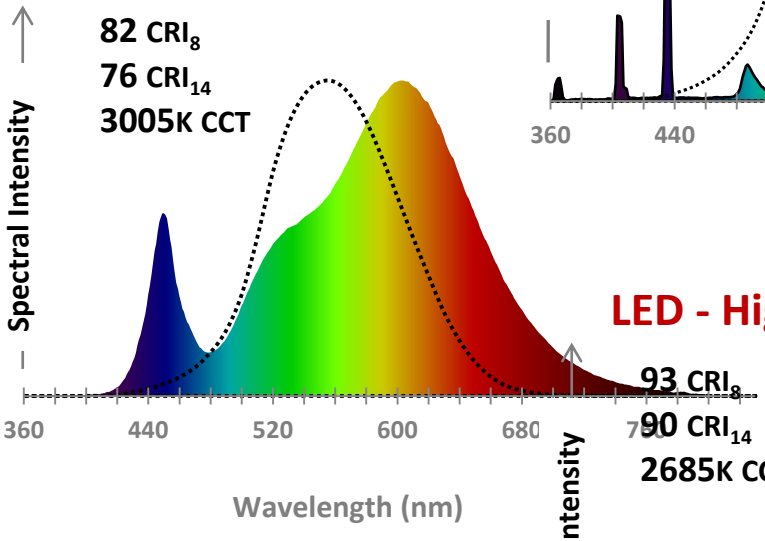
## Halogen (16.8 lm/W)



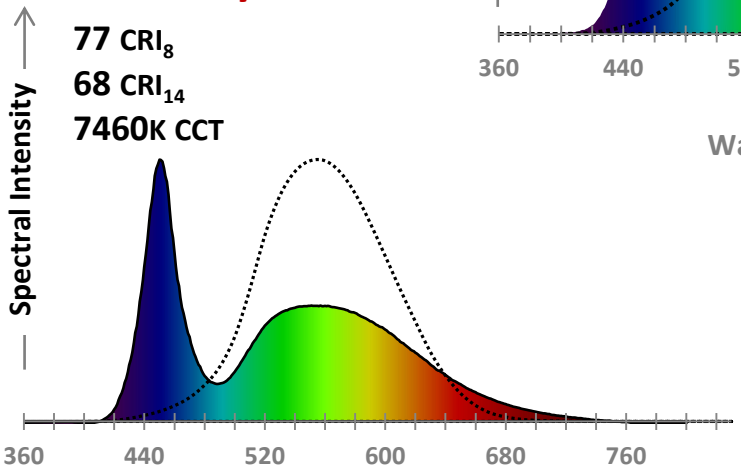

## CFL (63.5 lm/W)



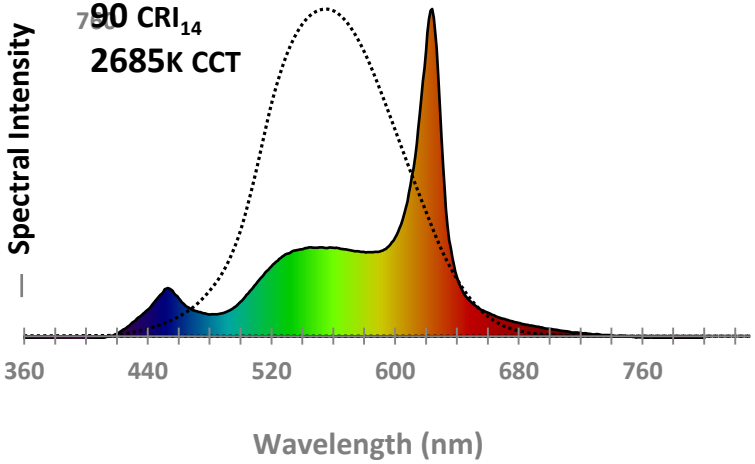

## LED - #1 on TopTen (62.9 lm/W)




## LED - Early Genera




## LED - High CRI (54.0 lm/W)



# Aesthetically Critical Applications – Hard to Beat Incandescents in Certain Places

- Red-dominated light is biologically important to us – it's the light we associate with sunset and with flame. For most of human history, this has been our cue to go to sleep.
- Blue-dominated light = mid-day sun = wake up.
- Our indoor lives now increasingly dominated by fluorescent and LED sources, either directly (overhead lighting) or indirectly (backlit TVs, monitors, tablets and cel phones). These tend to be blue-dominated light sources – they start out by making blue or ultraviolet light, and then use phosphors to down-convert that to the other colors of the spectrum.
- Not surprising that we are experiencing more insomnia than ever as our reliance on blue light sources increases – they are telling our brains to wake up at precisely the time we want to go to sleep.
- Our brains are also trained to associate dimmed light with more oranges and reds in the color. CFLs and LEDs struggle to deliver that experience, though the newest LED technologies can warm in color as they are dimmed.
- 2X incandescents have a role to play in efficient lighting portfolios.

# The Old Way:
# Take this, it's good for you

=

# The New Way:
# Buy this, it's awesome


=

# Thank You

My contact information:

Chris Calwell
ccalwell@ecova.com
970-259-6801 x301

1199 Main Avenue, Suite 242
Durango, CO 81301
ecova.com

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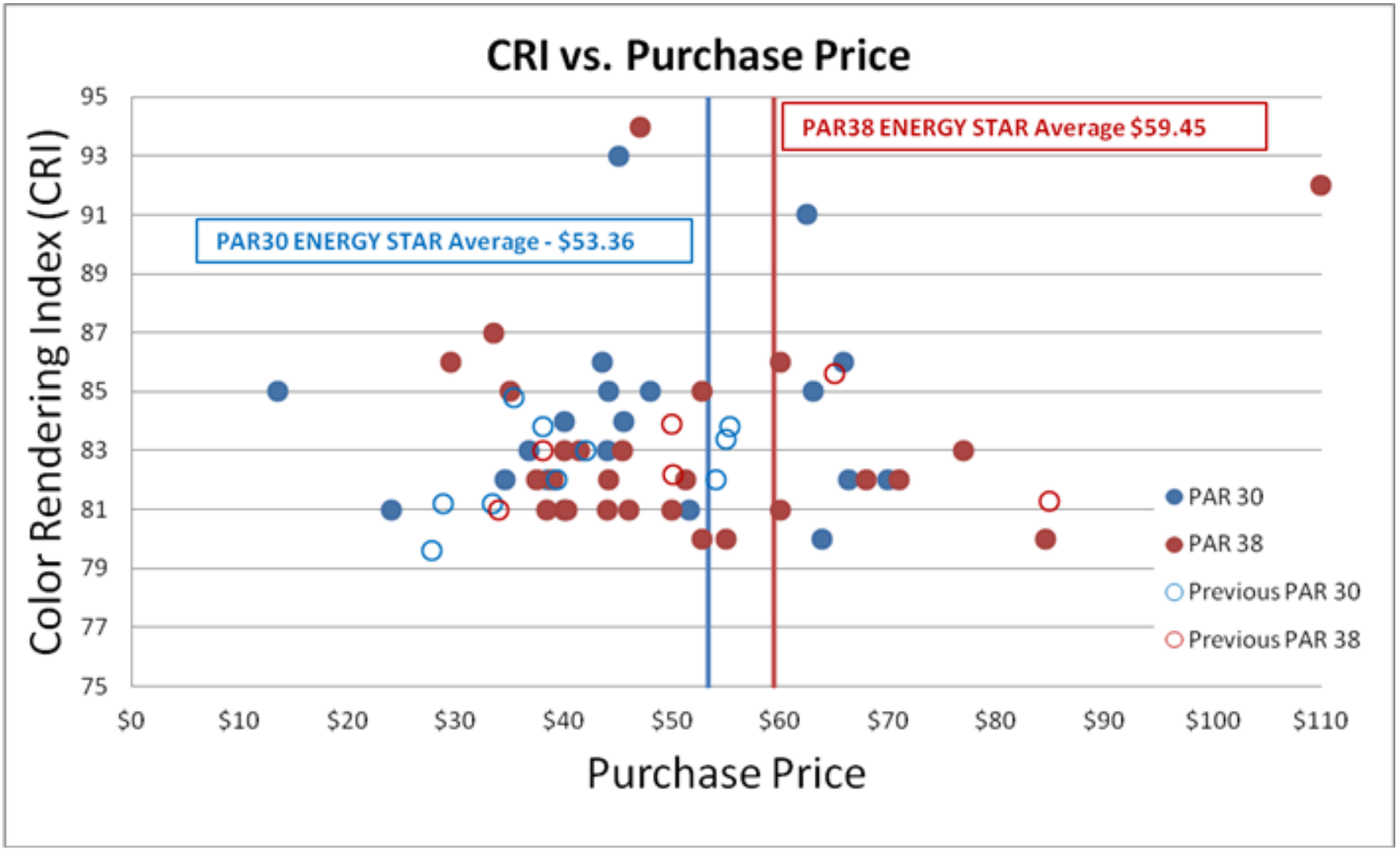
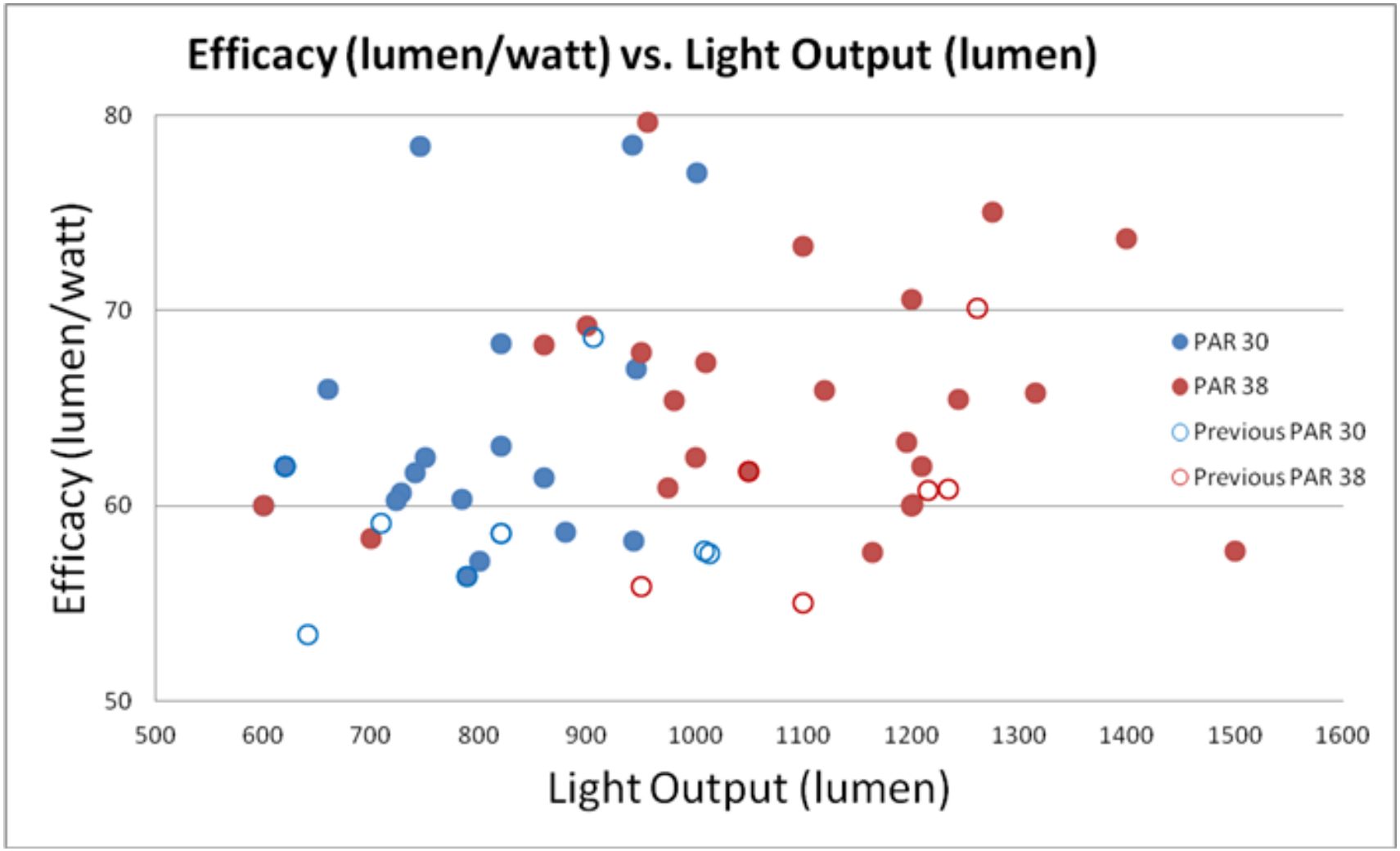
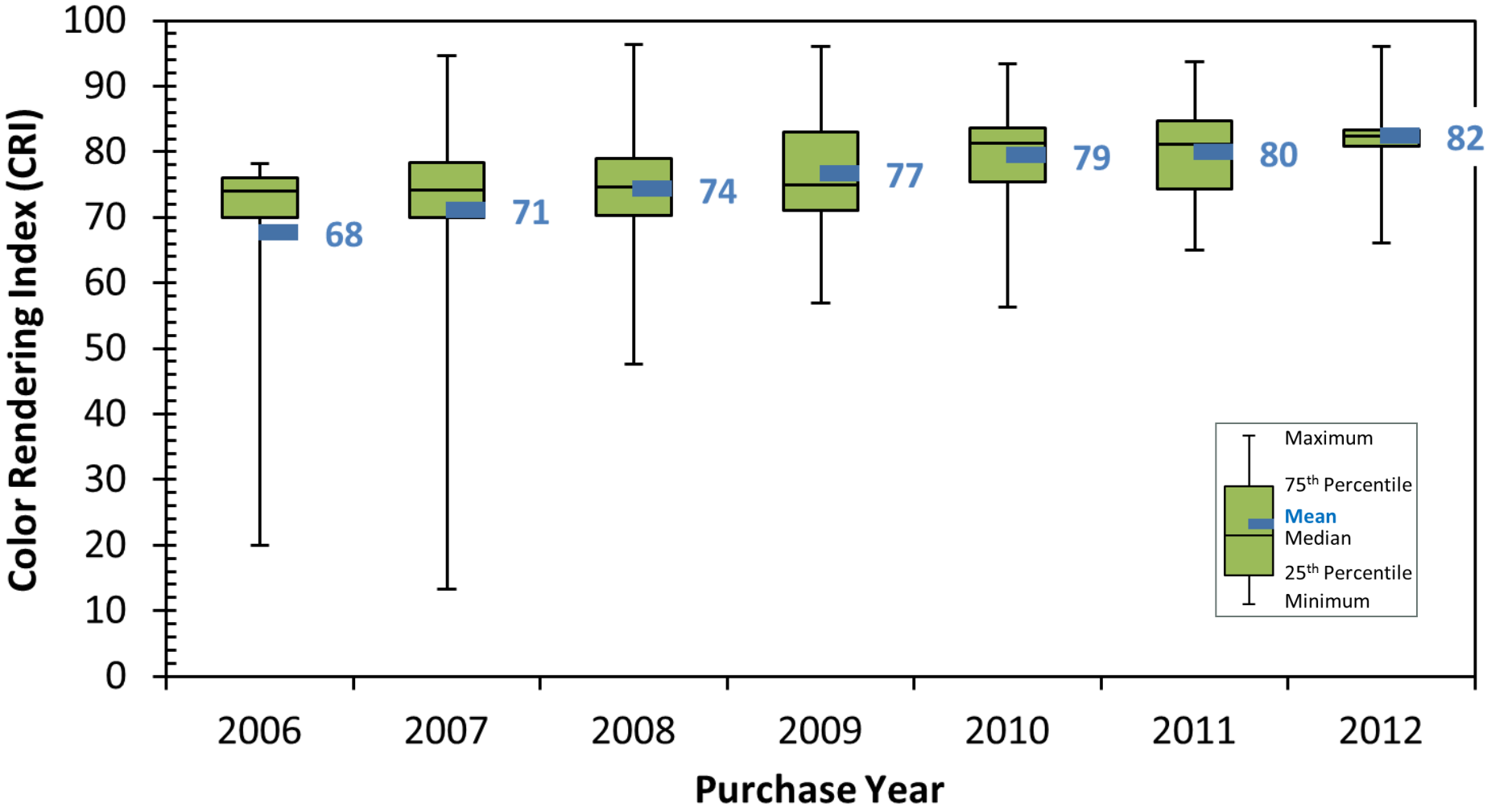


# PAR 38s Continue to Be Much Brighter than PAR 30s & Average Efficiencies of the Best Models Are Rising Fast



# Changes in Typical LED Color Rendering Index (CRI)




Source: US DOE, CALiPER Year in Review 2012, http://www1.eere.energy.gov/buildings/ssl/reports.html