LED Lighting in Commercial Spaces: Quality and Performance

Better Buildings by Design

Burlington, Vermont

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Outline

- State of LED Lighting Market
- Lighting Design and Economics
- Case Studies
- Tools and Resources
- Product Selection
- Color Quality

"Energy Savings Potential of Solid State Lighting in General Illumination Applications"
U.S. DOE, January 2012

LED Lighting Market Potential

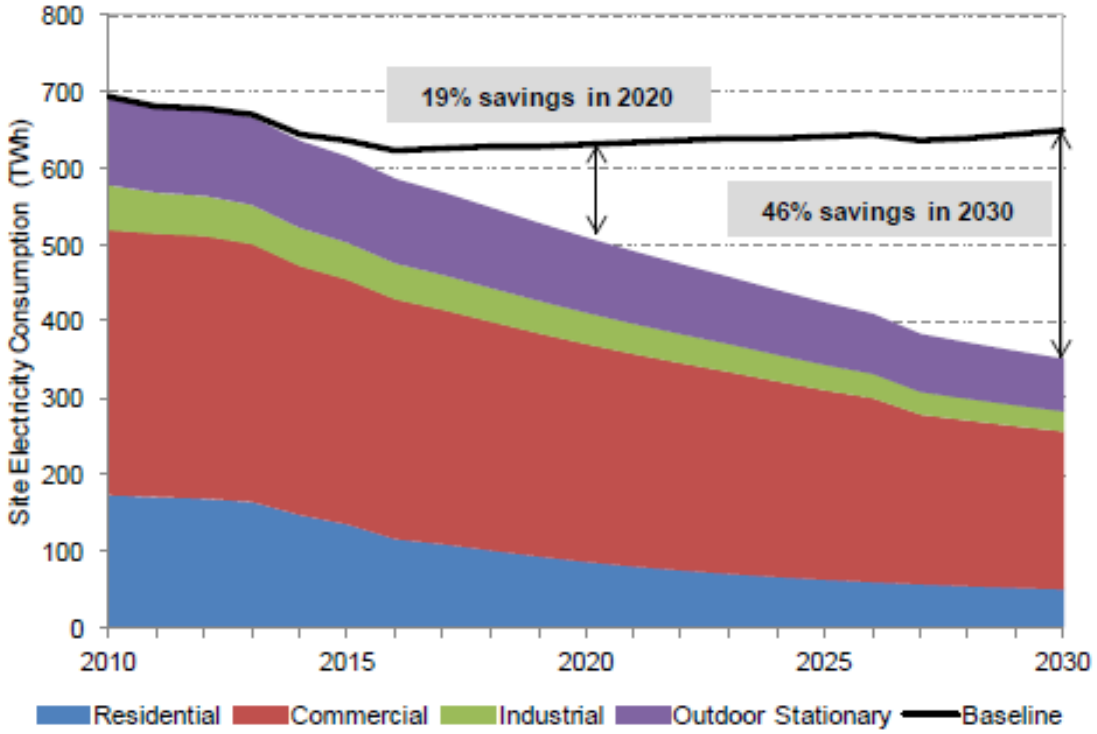


Figure 7.1 Total U.S. Lighting Energy Consumption Forecast, 2010 to 2030

Savings 2010-2030 tWh

- Res 1,009 38%
- C&I 1,663 62%

LED Lighting Market Potential

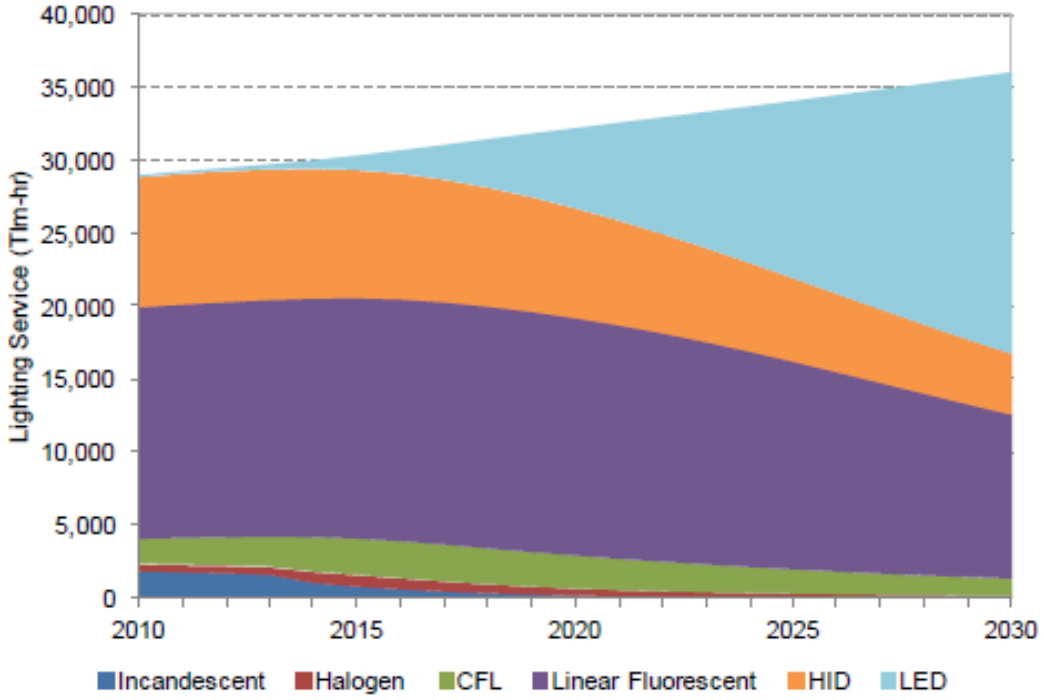


Figure 7.2 Total U.S. Lighting Service Forecast, 2010 to 2030

2030: Lumen-Hours

- LED
  - 74% Sales
  - 50% Base Service

DESIGNLIGHTS CONSORTIUM®

“Adoption of Light-Emitting Diodes in Common Applications”
U.S. DOE, April 2013, revised May 2013

Energy Savings Potential

- 2012
  - 49 million LEDs installed
  - Energy savings: 71 TBTu
  - Cost savings: $675 million
- Potential (socket saturation)
  - Energy savings: 3.9 quads
  - Cost savings: $37 billion

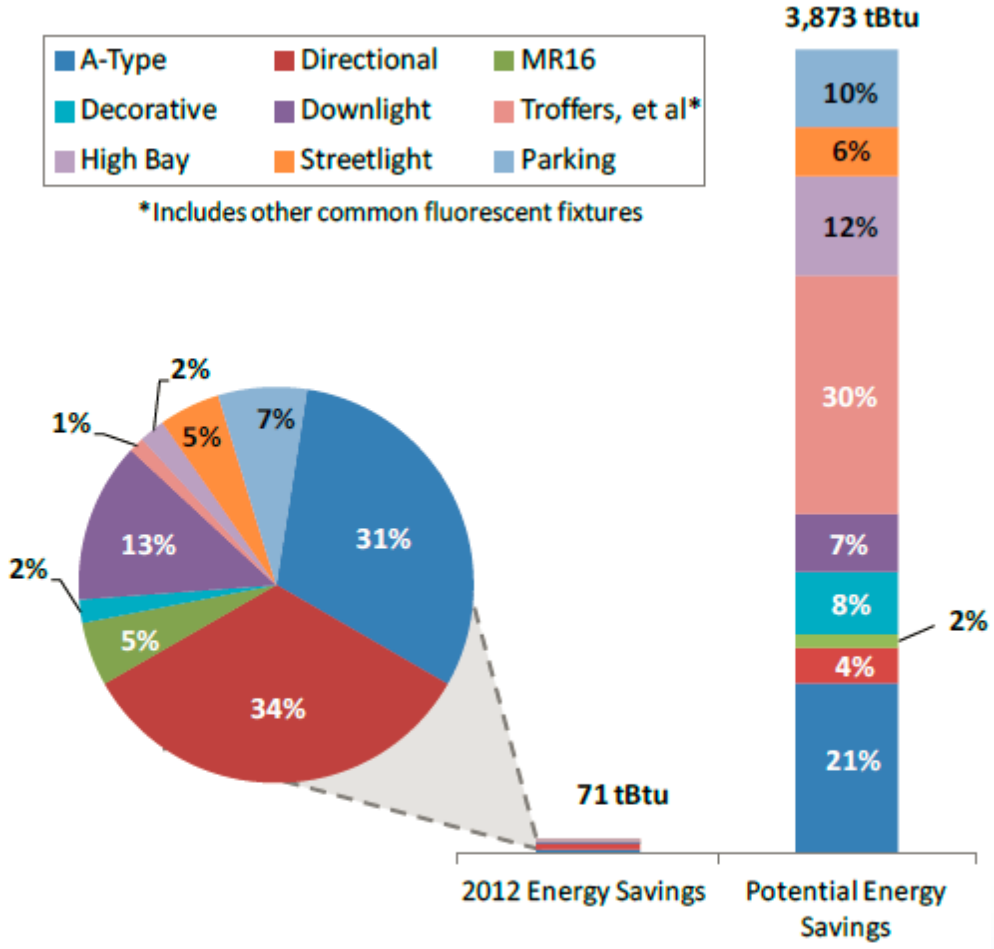


Figure ES.1 – Comparison of Current and Potential Source Energy Savings

Energy Savings Potential

- 2012
  - 49 million LEDs installed
  - Energy savings: 71 TBTu
  - Cost savings: $675 million
- Potential (socket saturation)
  - Energy savings: 3.9 quads
  - Cost savings: $37 billion
- 2030 Forecast
  - LEDs are 75% of lighting sales
  - Energy savings: 3.4 quads

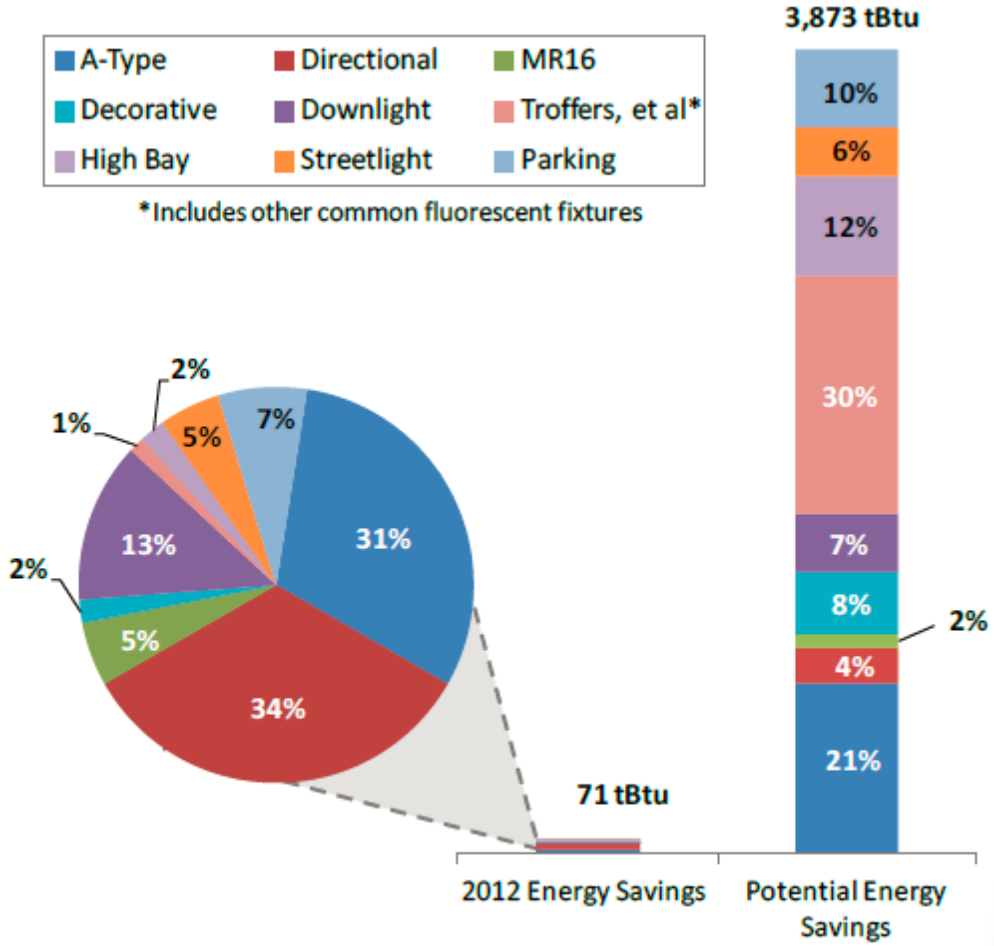
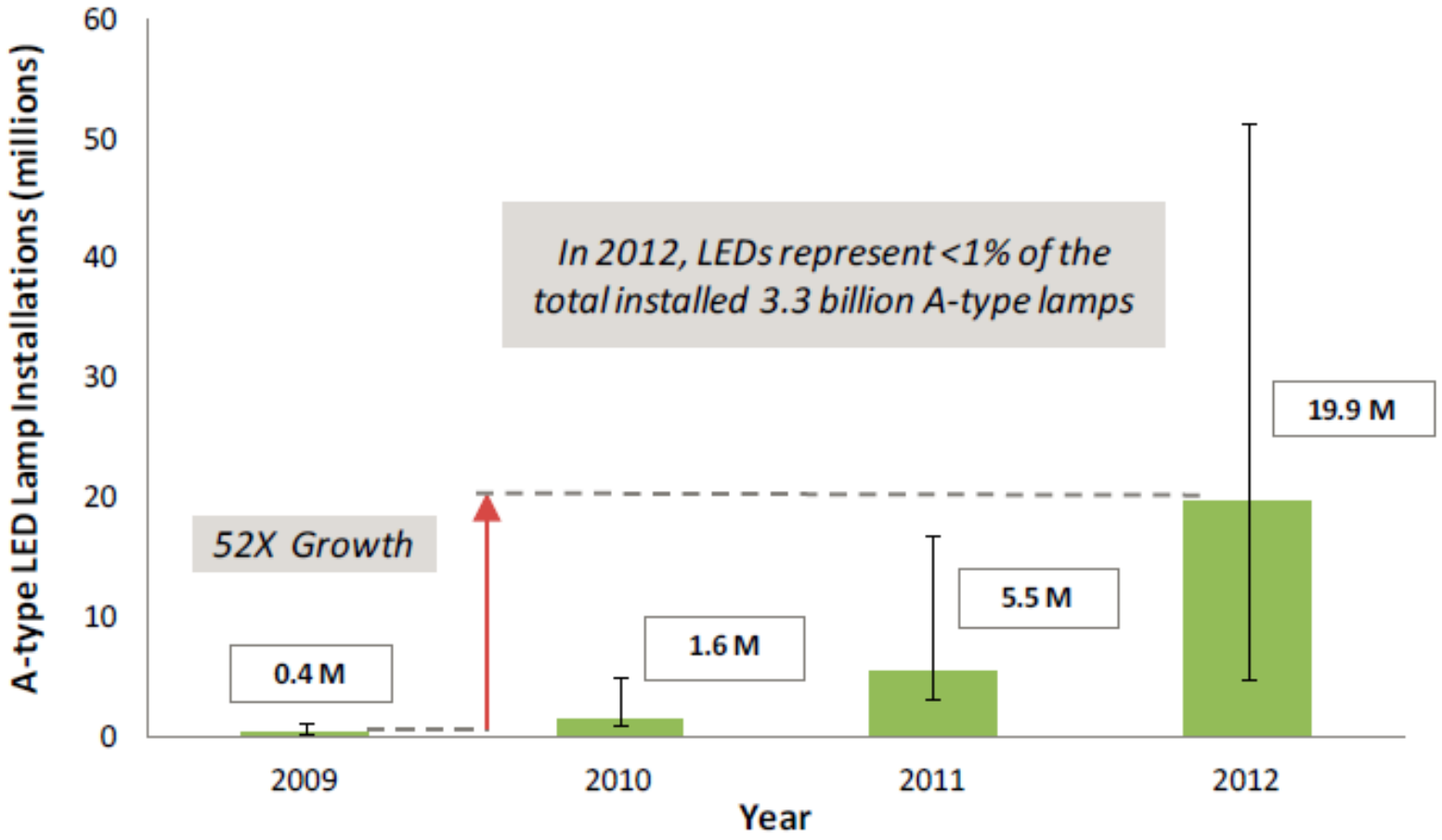


Figure ES.1 – Comparison of Current and Potential Source Energy Savings

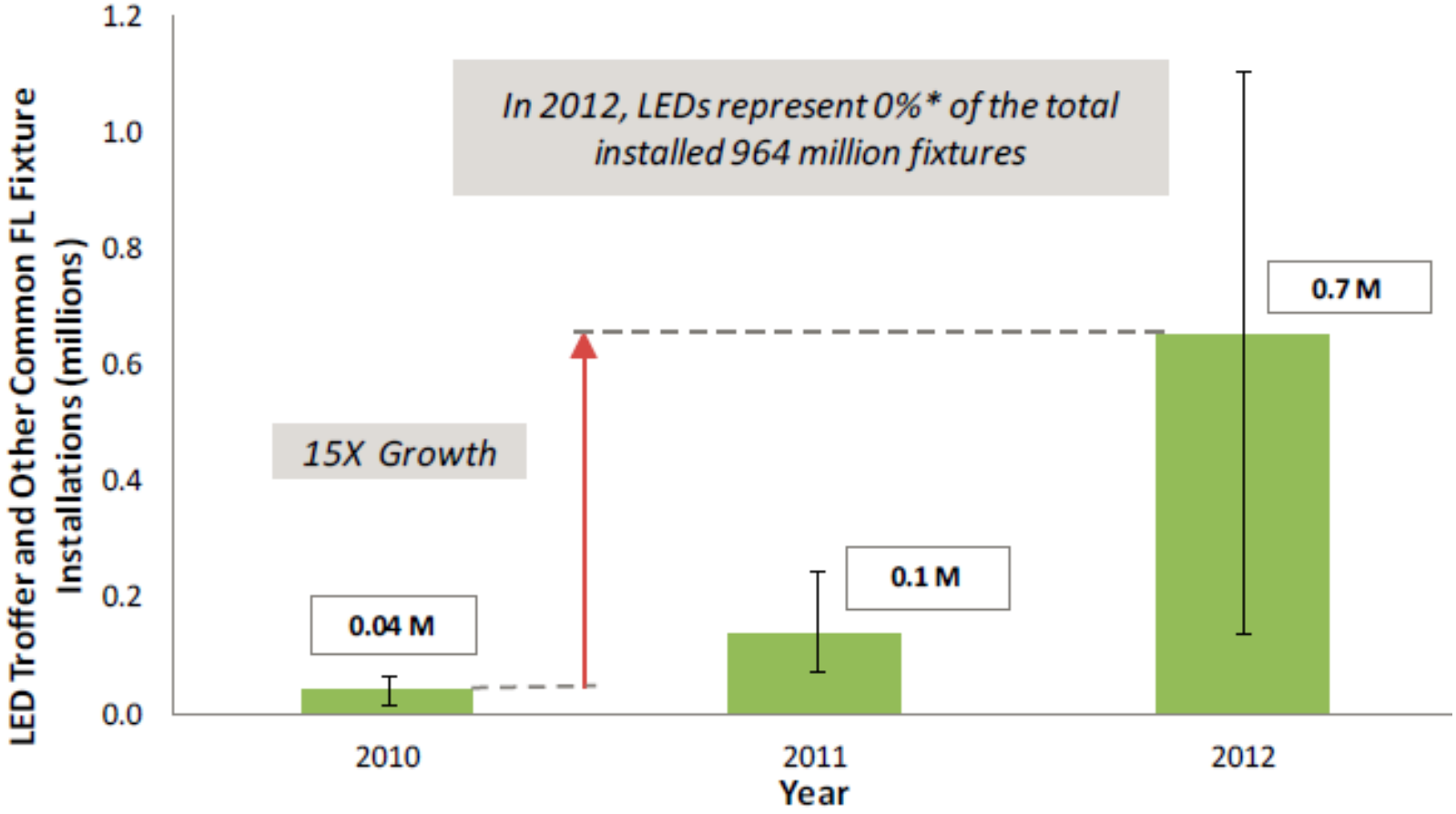
Adoptions is… Growing



*Upper and lower bounds on each bar represent the range of market estimates

Figure 2.1 – Installed Base Estimates for LED A-Type Lamps

Adoptions is… Growing



*Values less than 0.1% are considered negligible.
Upper and lower bounds on each bar represent the range of market

Figure 3.6 – Installed Base Estimates for LED Troffers and Other Common Fluorescent Fixtures[37]

Adoptions is… Growing

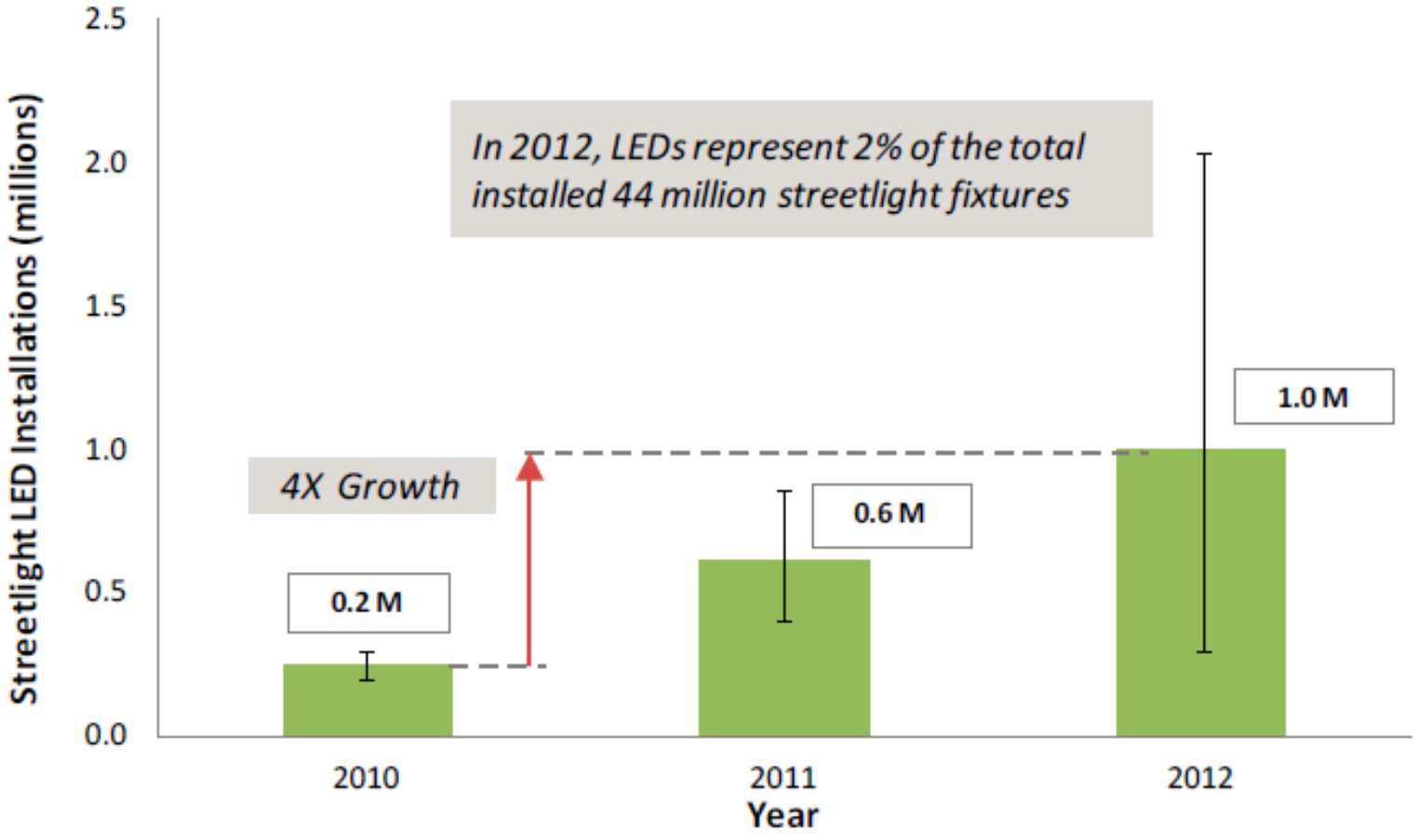
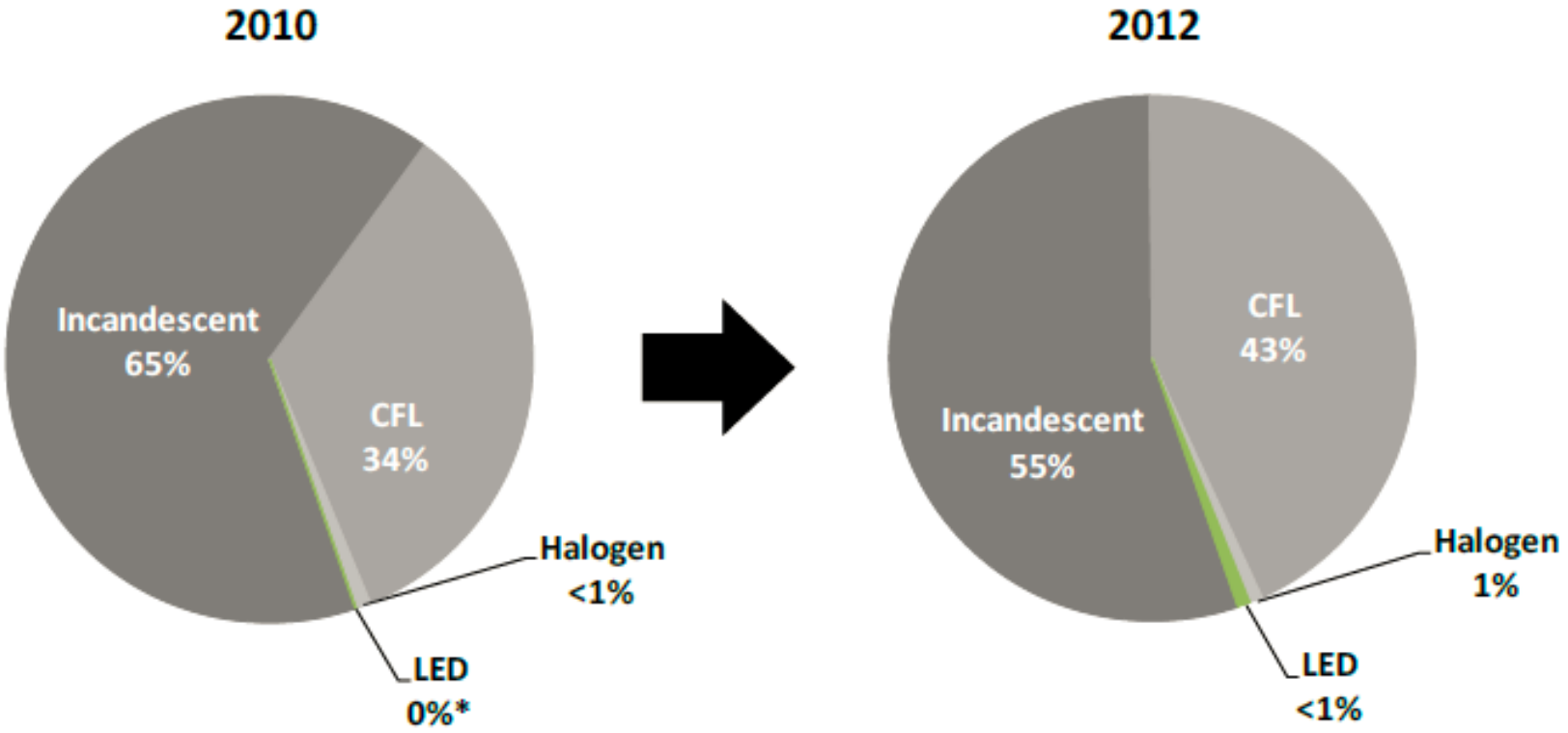


Figure 4.1 – Installed Base Estimates for LED Streetlight Luminaires[53,54]

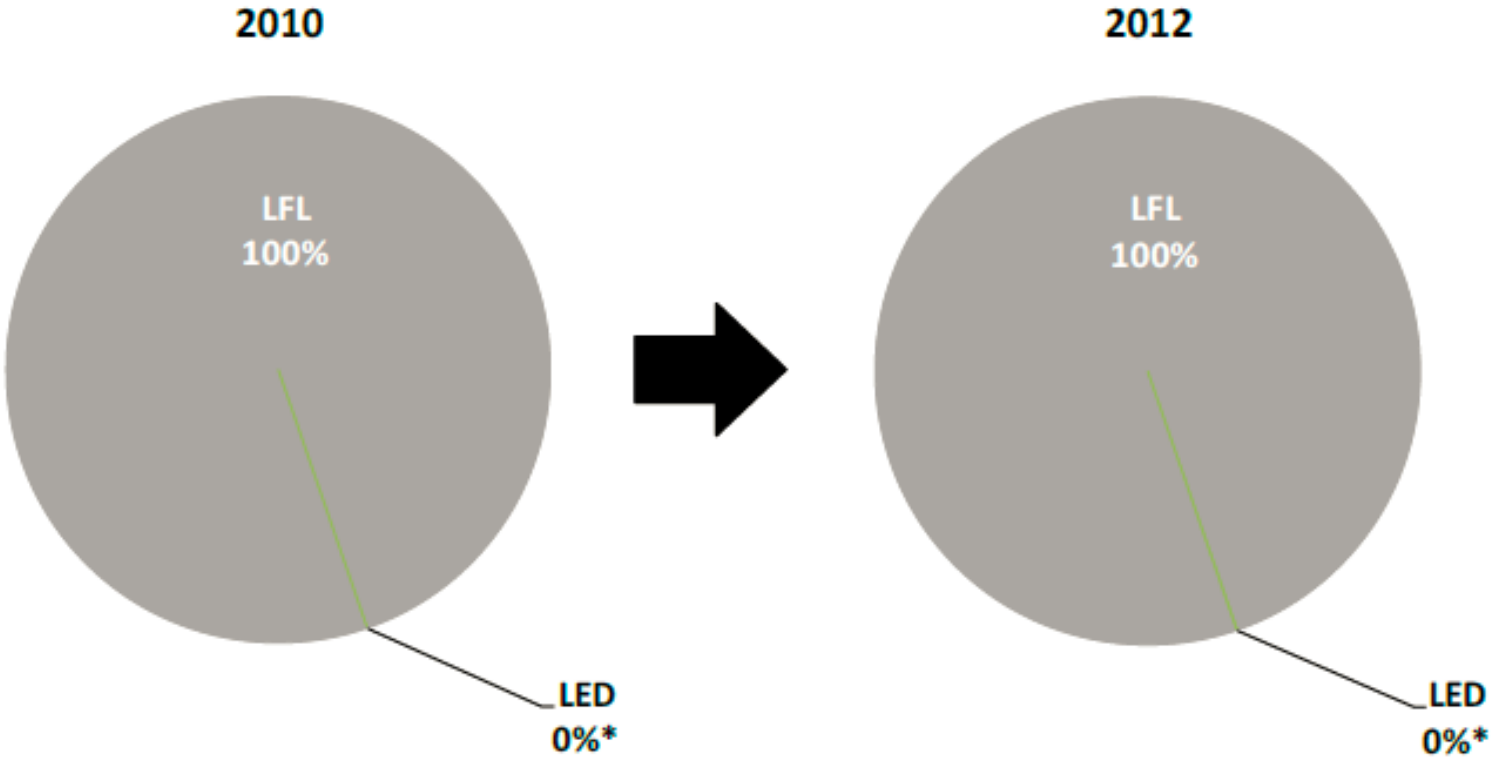
… And It Needs to Keep Growing



*Values less than 0.1% are considered negligible

Figure 2.2 – A-Type Lamp Installed Base

… And It Needs to Keep Growing



*Values less than 0.1% are considered negligible

Figure 3.7 – Troffer and Other Common Fluorescent Fixture Installed Base

… And It Needs to Keep Growing

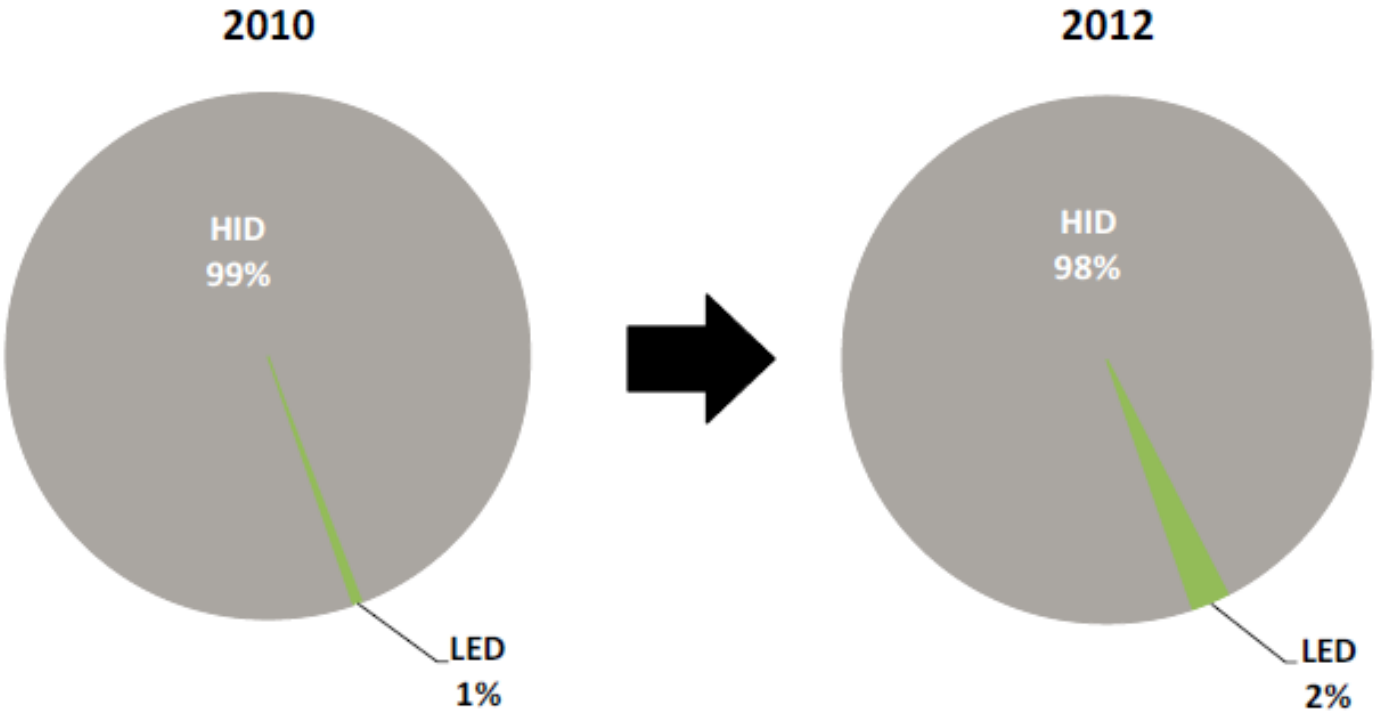


Figure 4.2 – Streetlight Luminaire Installed Base

The Mission of Lighting Solution Providers

Bring Products to Market Based on 2 Major Criteria

- *Meeting the Illumination Performance Requirements*

- *Meeting the Economic Performance Requirements*

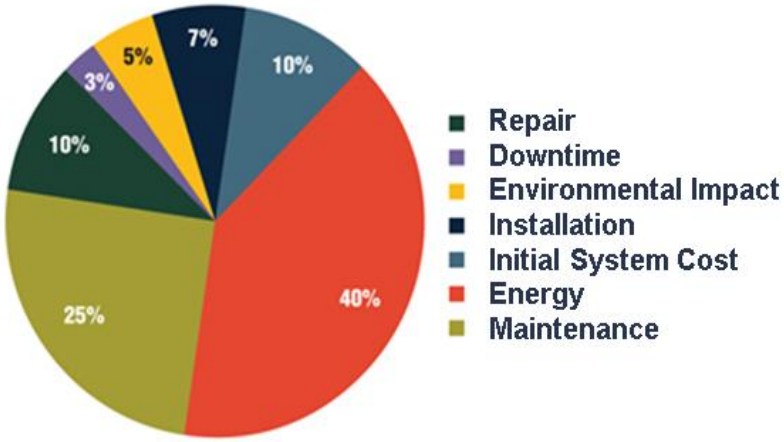
Life-Cycle Cost Analysis Justifies Adoption

Goal:

Maintained Illumination Performance

Maintained Economic Performance

Throughout the Life of the Application



Note: Proportions are Arbitrary

Does LED technology provide the opportunity to provide higher value than traditional sources???

- Energy Consumption
- Service Life
- Heat (i.e. HVAC load, etc.)
- Color Quality
- High Luminous Flux Options
- Precise Optical Control
- Dimming / Controllability

Specifying LED Solutions

The Goal…

A Process That

Enables the Required Performance Expectations to be Met

Essential Elements

A Specification Development Process that:

1. Defines the Required Sustainable Illumination Performance

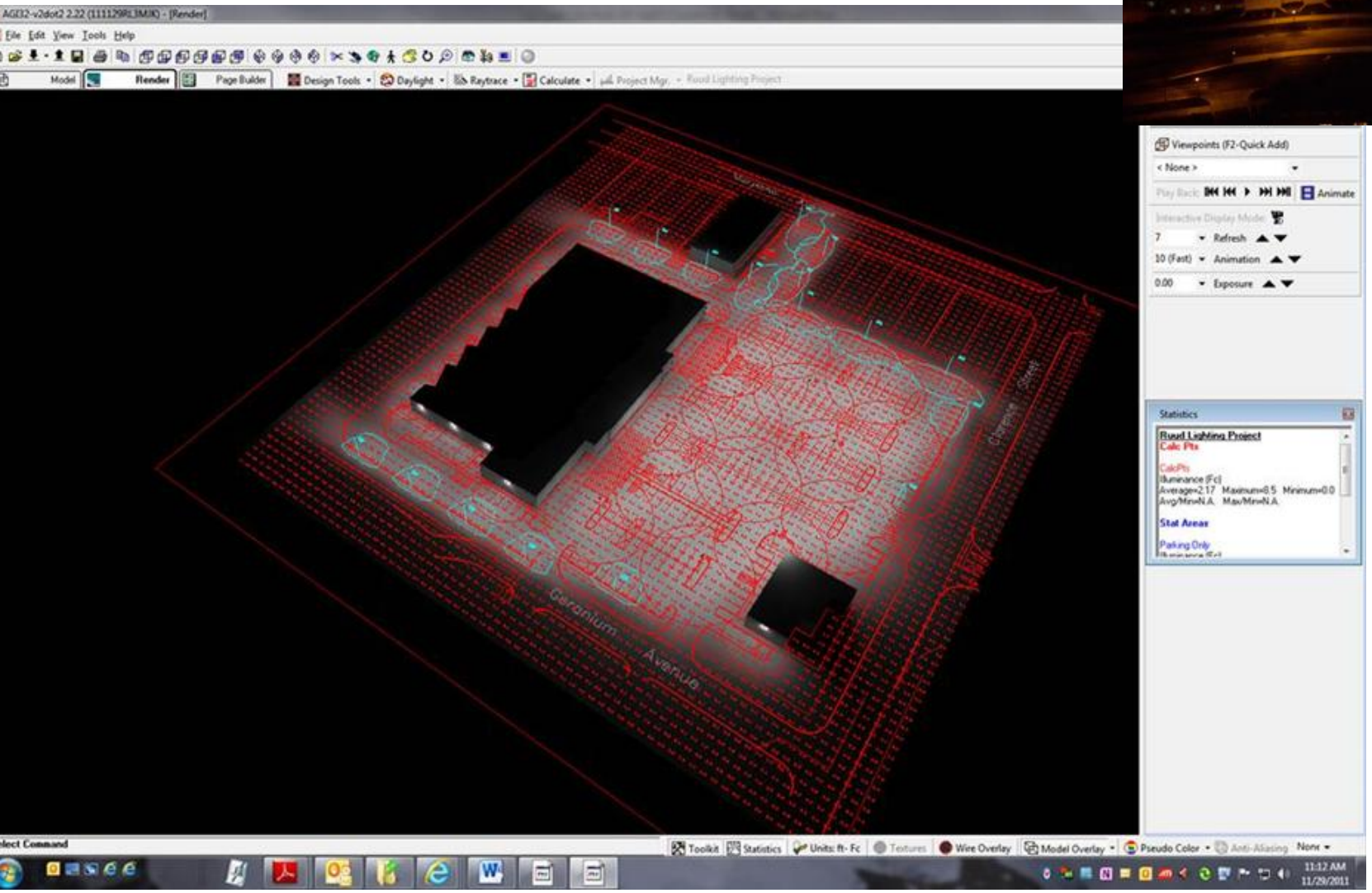
Example:

Illumination Performance Requirements

- **1 fc Minimum Illuminance**
- **10:1 Max/Min Uniformity**

- **50,000 Hour Application Duration**

Lighting Design

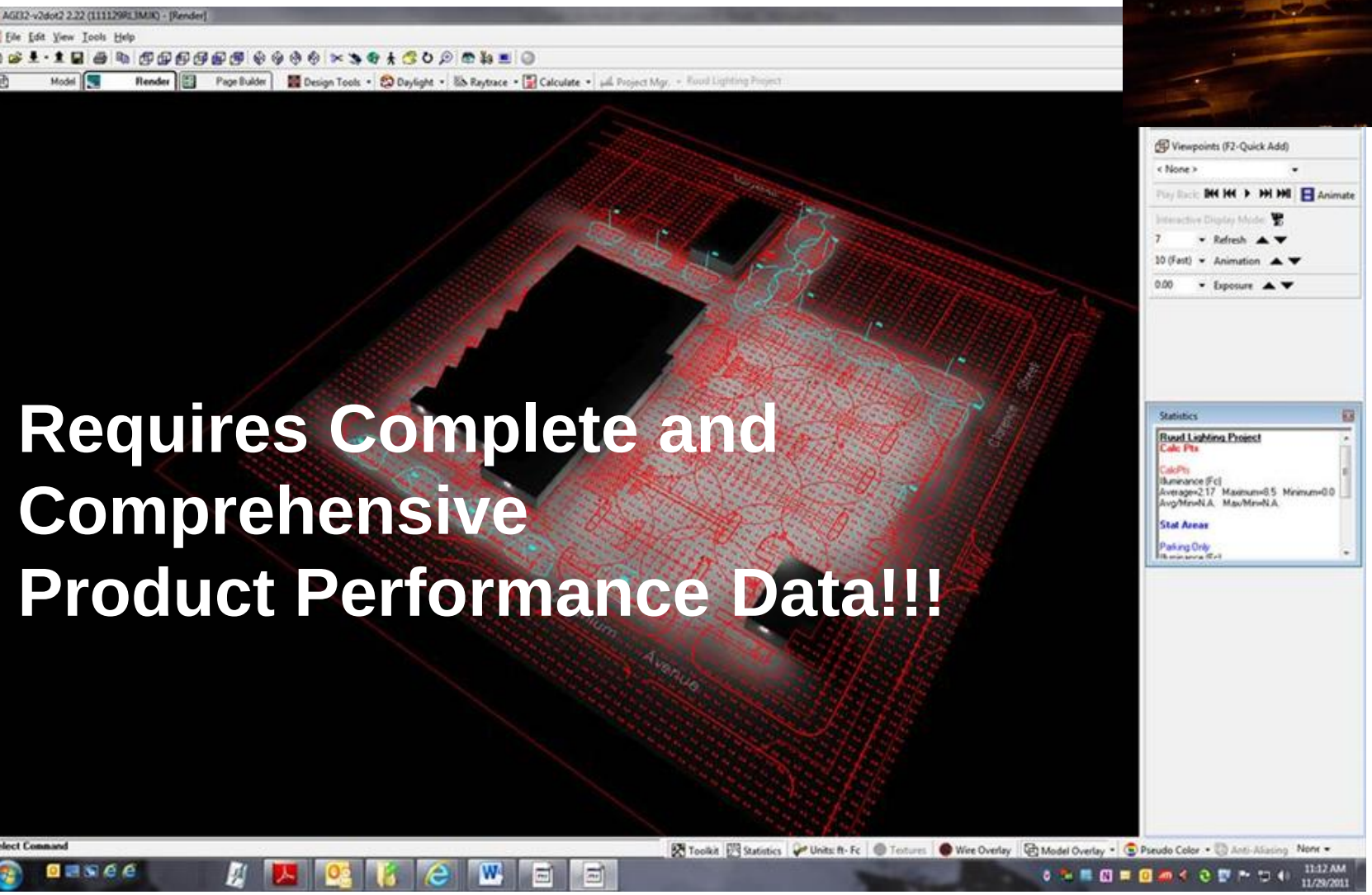


Retail 2009

System Power Comparison

LED – ~19 kW
Spec Grade HID – ~31 kW

The Value of Lighting Design



IESNA LM-79-08 Photometric Testing

– LM-79-08 **“<u>Bundles</u>”** the Effects of Many Luminaire System Variables

- Thermal Management
  - The Effectiveness of the Heat Sink
- Optical Control
  - Optical Precision
  - Optical Efficiency
- Electrical Power Efficiency (Driver Efficiency)
- Etc…

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

Building Technologies Program
SOLID-STATE LIGHTING TECHNOLOGY FACT SHEET

UNDERSTANDING LM-79 REPORTS

In 2008, the Illuminating Engineering Society of North America (IES) published LM-79-08, *Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products.* Why are special test procedures required for this technology, and what kind of information is gleaned from testing conducted using this new method?

A goniophotometer is used to characterize spatial distribution of light. A mirror travels around a light source and reflects light to a detector, providing intensity measurements over a range of angles. (Photo credit: ITL Boulder)

LM-79 testing captures performance characteristics of products that feature solid-state lighting (SSL) technology, including light-emitting diodes (LEDs). This testing provides a snapshot of performance under specified operating conditions at some point in the life of a product, usually at the beginning of operation—these are referred to as initial measurements. It does not address lifetime ratings, changing performance over time (e.g., lumen maintenance), or LED case temperature.[1] The LM-79 method is applicable to integrated LED products, such as luminaires and replacement lamps. It is not applicable to LED packages, modules, or arrays (herein collectively referred to as LED light sources).[2]

LM-79 data enables objective product comparisons, allows for evaluation relative to performance requirements, and is required by voluntary labeling programs such as LED Lighting Facts and ENERGY STAR®.[3] Although LM-79 does not prescribe a report format or the minimum content, a substantial list of "typical items reported" is provided. Key types of measurements addressed in the document include electrical characteristics, lumen output, spatial distribution of light, and color attributes. The DOE fact sheet, "LED Color Characteristics," (which is available online at *www.ssl.energy.gov/factsheets.html*) is dedicated to a discussion of color-related metrics that may be included in LM-79 reports.

Electrical Characteristics

A variety of electrical measurements may be conducted as part of LM-79 testing, including but not limited to:

- Input voltage, expressed in volts (V). Testing is performed with the SSL product operated at its rated input voltage.
- Input current, expressed in amperes (A). Input current can be either direct current (DC) or alternating current (AC), depending on product design. Note that this metric is not equivalent to the current supplied to a given LED light source (i.e., LED drive current), which often cannot be measured directly without damaging the product.[4]
- Input power, expressed in watts (W). Input power is essential for determining energy savings.
- Power factor (PF), is a power quality metric reported as a unitless decimal value between zero and one. PF is calculated by dividing input power by the product of input voltage and input current.

Lumen Output and Luminous Efficacy

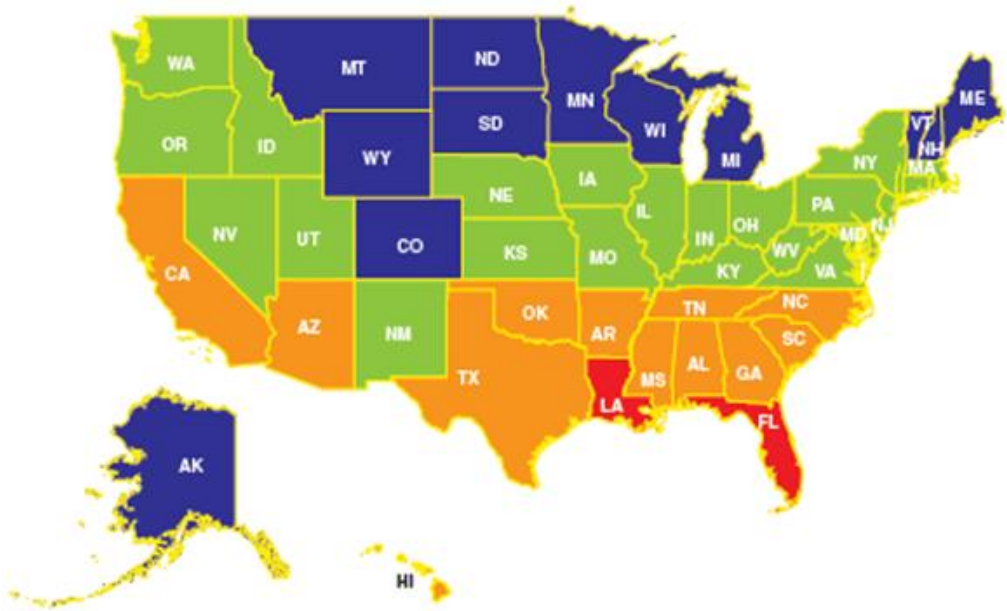
Light output—more formally referred to as luminous flux—is expressed in lumens (lm).[5] Lumen output is a more meaningful metric than input power when establishing product equivalency because the ratio of total lumen output to input power can differ from product to product.[6] This quotient is termed luminous *efficacy* and is expressed in lumens per watt (lm/W).

Relative vs. Absolute Photometry

Non-SSL products are typically measured using *relative* photometry, for which lamps and ballasts are tested separately from luminaires. Luminaire *efficiency* is calculated by dividing the total lumen output of the luminaire by the product of the rated

1 Long-term performance is discussed in the DOE fact sheet, "Lifetime of White LEDs," which is available at www.ssl.energy.gov/factsheets.html.
2 The term LED light source is defined in IES LM-80-08. See IES RP-16-10 for formal definitions of related terms.
3 For more information on these programs, please visit www.lightingfacts.com and www.energystar.gov.
4 LED drive current is nominal (i.e., reported by manufacturer), this metric is discussed in the DOE fact sheet, "Lifetime of White LEDs."
5 Photometric quantities are based on photopic visual adaptation. For more on this topic and the use of scotopic/photopic (S/P) ratios, see IES TM-12 and the 10th edition IES Lighting Handbook.
6 See the DOE fact sheet, "Establishing LED-Equivalency," for more on this topic.

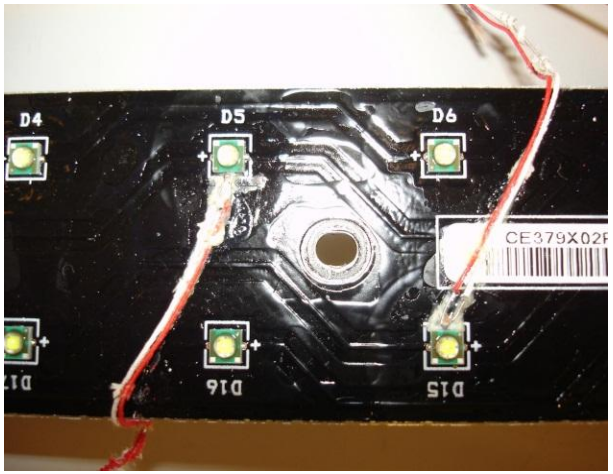
LED Luminaire Lumen Maintenance Factors Example



Zone*	Input Power Designator[2]	Initial LMF	25K hr LMF (Projected[3])	50K hr LMF (Calculated[4])	100K hr LMF (Calculated[4])
5°C (41°F)	L (100%)	1.05	0.97	0.91	0.76
	Q (46%)	1.05	0.98	0.93	0.81
10°C (50°F)	L (100%)	1.04	0.95	0.88	0.74
	Q (46%)	1.04	0.97	0.91	0.79
15°C (59°F)	L (100%)	1.03	0.94	0.86	0.71
	Q (46%)	1.03	0.96	0.89	0.77
20°C (68°F)	L (100%)	1.01	0.92	0.84	0.69
	Q (46%)	1.01	0.95	0.88	0.75
25°C (77°F)	L (100%)	1.00	0.90	0.82	0.65
	Q (46%)	1.00	0.93	0.86	0.73

Look for Justification of Lumen Maintenance Data

- **IESNA LM-80-08 and IESNA TM-21-11 (Lumen Maintenance Performance Data)**
  Outdoor Luminaire Lumen Maintenance Data sets are created using correlated in-situ luminaire test methods (i.e. LED chip package temperature (T_s) measurement(s) obtained with the LED chip package(s) operating in given luminaire and in a given stabilized ambient environment. The T_s temperature(s) is correlated directly to the LED chip package manufacturer's LM-80-08 data, in conjunction with TM-21-11 described extrapolation and interpolation methods, to form data sets predicting luminaire lumen maintenance for various luminaire average ambient operating conditions.).

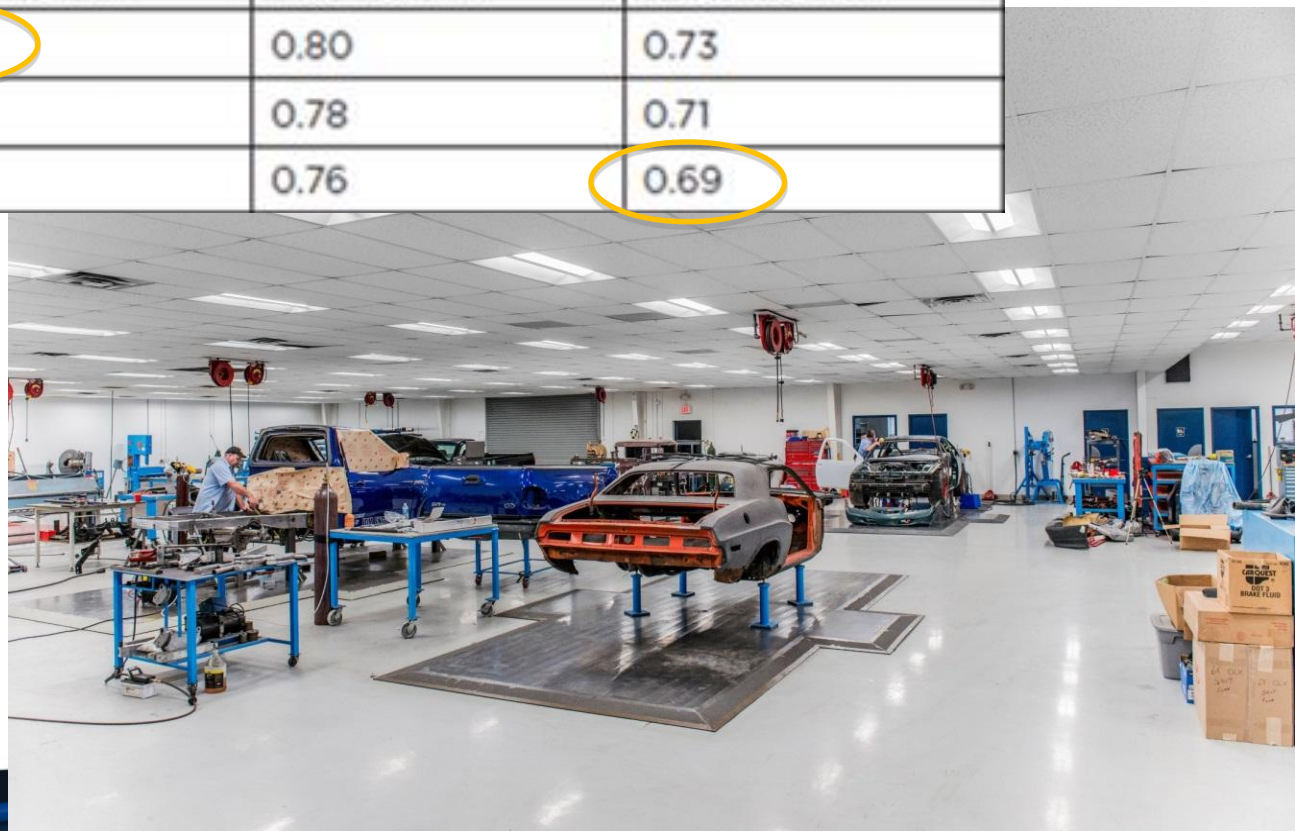


25K hr LMF (Projected[3])	50K hr LMF (Projected[3])	100K hr LMF (Calculated[4])
1.07	1.03	0.96
1.07	1.03	0.94
1.06	1.01	0.92
1.05	1.01	0.93

3 In accordance with IESNA TM-21-11, **Projected Values** represent interpolated values based on time durations that are within six times (6X) the IESNA LM-80-08 total test duration (in hours) for the device under testing ((DUT) i.e. the packaged LED chip).

4 In accordance with IESNA TM-21-11, **Calculated Values** represent time durations that exceed six times (6X) the IESNA LM-80-08 total test duration (in hours) for the device under testing ((DUT) i.e. the packaged LED chip)

Ambient Temp	50K hrs LMF	75K hrs LMF	100k hrs LMF
25°C (77° F)	0.87	0.80	0.73
30°C (86° F)	0.85	0.78	0.71
35°C (95° F)	0.84	0.76	0.69



Best Economic Opportunities

Parking Structures

- **Accessible Luminaires**
- **Many are 24/7/365 facilities**
- **Typically low average occupancy levels (15% or less)**

Parking Structures

IESNA REQUIREMENTS: RP-20-98

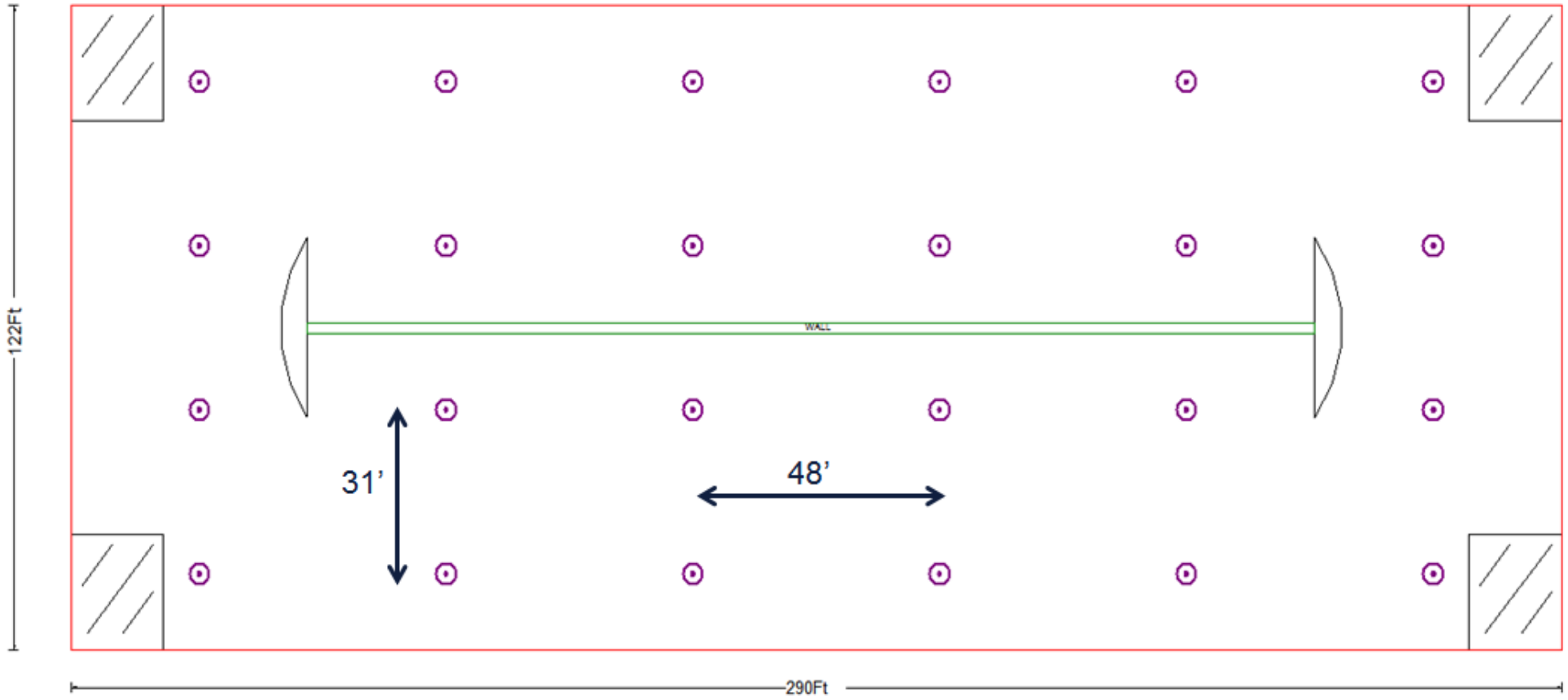
Table 2: Recommended Maintained Illuminance Values for Parking Garages

	Miminum Horizontal[2] Lux	fc[4]	Maximum/Minimum Horizontal Uniformity Ratio[3]	Minimum Vertical[5] Lux	fc[4]
Basic[1]	10	1.0	10:1	5	0.5
Ramps[6]					
Day[7]	20	2.0	10:1	10	1.0
Night	10	1.0	10:1	5	0.5
Entrance Areas[8]					
Day[7]	500	50		250	25
Night	10	1.0	10:1	5	0.5
Stairways[9]	20	2.0		10	1.0

Parking Structure Application Example

Site Conditions:

- Mounting Height: 10.5’
- Luminaire Spacing: 58’ x 31’
- Reflectances: 30-30-20%



Luminaire Details

	Existing PSMH	LED A	LED B	LED C
Lamp Lumens	14,000	-	-	-
Lamp Wattage	150W	-	-	-
Luminaire Lumens	10,911	8,576	5,758	3,870
Luminaire Wattage	185W	105W	68W	50W
CCT (°K)	4000K	5700K	5700K	5700K
CRI	68	70	70	70

Application Results

	RP-20	Existing PSMH	LED A	LED B	LED C
Luminaire Wattage	-	188W	105W	68W	50W
Minimum Maintained Illuminance (fc)	≥ 1.0	1.4	1.5	1.0	1.0
Max/Min Ratio	≤ 10	9.36	4.07	4.10	1.60

- Calculations utilize
  - LED lumen maintenance factors at 15˚ C and 100,000hrs (11.4 years)
  - PSMH lumen maintenance factor of 0.75 (75% output at 6,000hrs)

Total Cost of Ownership Evaluations

Fixture Information	150W PSMH		Fixture Information	VG						
Fixture Application	PARKING GARAGE		Fixture Application	PARKING GARAGE						
Number of Fixtures	200		Number of Fixtures	200						
Voltage	120-277		Voltage	120-277						
Lamp Type	150W PSMH		Lamp Type	VG						
System Watts	185		System Watts	50		High (20%)	0			
						Low (80%)	0			
Operation			Operation				0			
Cost per kWHr	$0.10		Cost per kWHr	$0.10						
Days per Year	365		Days per Year	365						
Hours per Day	24		Hours per Day	24						
Annual Hours of Operation	8760		Annual Hours of Operation	8760						
Maintenance			Maintenance							
Per Fixture Relamp Cost	$50		Per Fixture Relamp Cost	$0						
Maintenance Interval (Years)	1		Maintenance Interval (Years)	0						
Per Fixture Ballast Cost	$50		Per Fixture Ballast Cost	$0						
Maintenance Interval (Years)	10		Maintenance Interval (Years)	0						
									Assume an 11.4 year application life.	
									Lifetime	
Summary			Summary			150W PSMH vs. LED C			(X 11.4)	100K hours
Annual Energy Consumption (in watts)		324,120,000	Annual Energy Consumption (in watts)		87,600,000	73.0%	Energy Savings (%)			
Annual Energy Cost		$32,412	Annual Energy Cost		$8,760	$23,652	Annual Energy Savings		$269,633	
Annual Maintenance Cost		$11,000	Annual Maintenance Cost		$0	$11,000	Maintenace Savings		$125,400	
Total Annual Cost (Energy + Maintenace)		$43,412	Total Annual Cost (Energy + Maintenace)		$8,760	$34,652	Energy + Maint. Savings		$395,033	
						Payback in Years	1.7			

		Assume an 11.4 year application life.	
	150W PSMH vs. LED C	Lifetime	
		(X 11.4)	100K hours
73.0%	Energy Savings (%)		
$23,652	Annual Energy Savings	$269,633	
$11,000	Maintenace Savings	$125,400	
$34,652	Energy + Maint. Savings	$395,033	
Payback in Years	1.7		

Annual Savings and Payback

	LED C
Energy Savings	73%
Annual Energy Savings	$23,652
Maintenance Savings	$11,000
Annual Energy + Maintenance Savings	$34,652
Payback (in years)	1.7

Case Study Example

Parking Structure With Occupancy Controls

Why Should Lighting Controls Be Considered?

Improve Economic Performance

Regulatory Compliance

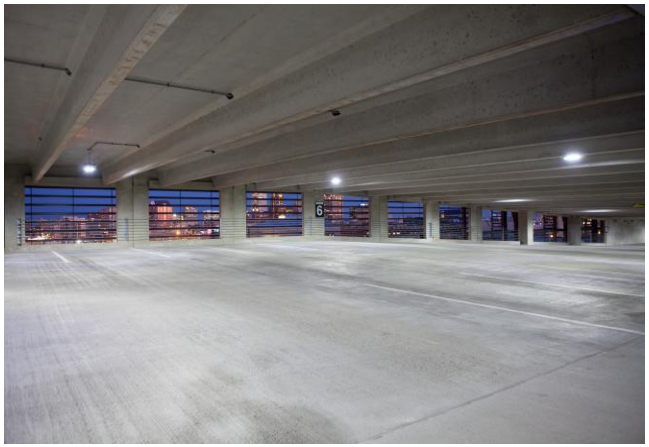
- Building Codes (ASHRAE 90.1, Title 24)

Social Responsibility

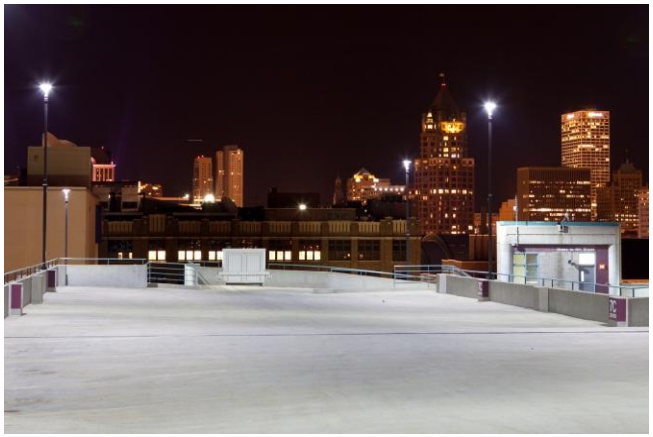
- LEED
- Green Initiatives

Parking Structure Application
Common Control Strategies

Daylighting



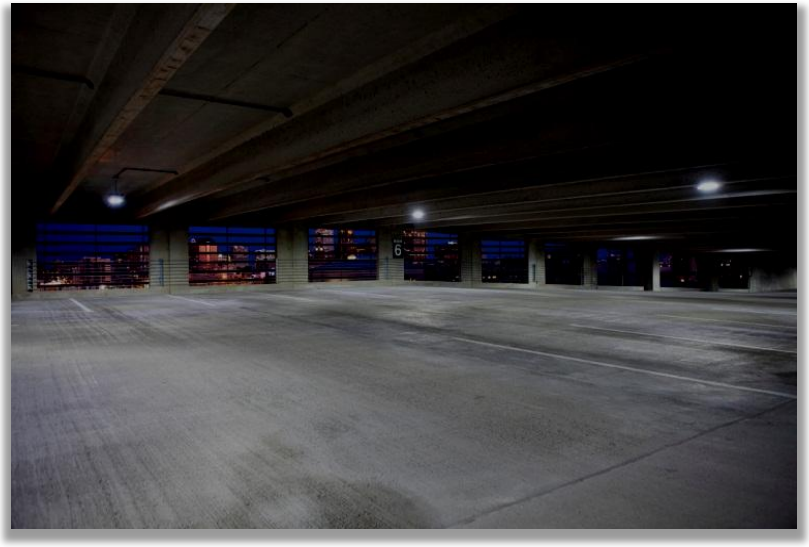
Occupant Detection

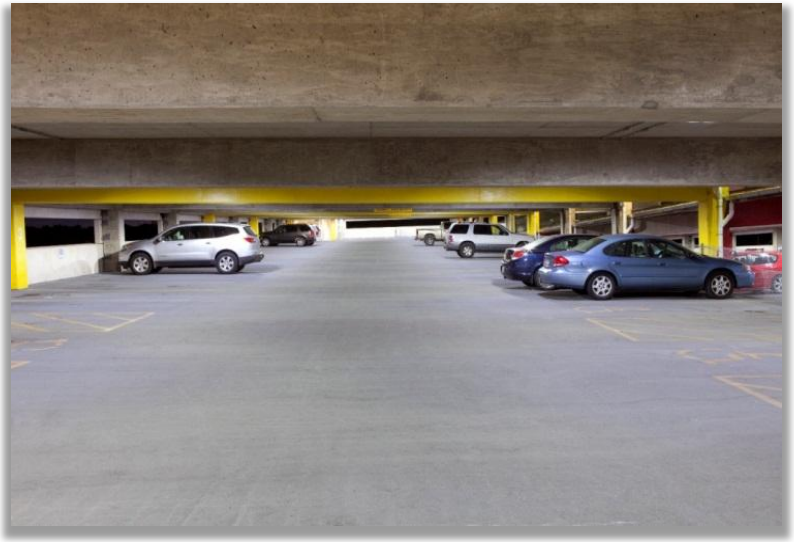


Daylighting & Occupant Detection

Payback Improvements

- Controls provide significant additional energy savings
- Example: Occupancy sensors in a parking structure
  - Reduce light output to acceptable minimums in the unoccupied space.
  - Aggregate energy savings over 80% and paybacks of less than 2 years are not uncommon





Parking Garage
Total Cost of Ownership Calcs

Fixture Information	150W PSMH
Fixture Application	PARKING GARAGE
Number of Fixtures	200
Voltage	120-277
Lamp Type	150W PSMH
System Watts	185
Operation	
Cost per kWHr	$0.10
Days per Year	365
Hours per Day	24
Annual Hours of Operation	8760
Maintenance	
Per Fixture Relamp Cost	$50
Maintenance Interval (Years)	1
Per Fixture Ballast Cost	$50
Maintenance Interval (Years)	10
Summary	
Annual Energy Consumption (in watts)	324,120,000
Annual Energy Cost	$32,412
Annual Maintenance Cost	$11,000
Total Annual Cost (Energy + Maintenace)	$43,412

Fixture Information	VG			
Fixture Application	PARKING GARAGE			
Number of Fixtures	200			
Voltage	120-277			
Lamp Type	VG			
System Watts	16	50	High (20%)	10
		7.5	Low (80%)	6
				16
Operation				
Cost per kWHr	$0.10			
Days per Year	365			
Hours per Day	24			
Annual Hours of Operation	8760			
Maintenance				
Per Fixture Relamp Cost	$0			
Maintenance Interval (Years)	0			
Per Fixture Ballast Cost	$0			
Maintenance Interval (Years)	0			
Summary				
Annual Energy Consumption (in watts)	28,032,000			
Annual Energy Cost	$2,803			
Annual Maintenance Cost	$0			
Total Annual Cost (Energy + Maintenace	$2,803			

150W PSMH vs. LED C w/controls		Assume an 11.4 year application life.
		Lifetime
91.4%	Energy Savings (%)	(X 11.4) 100K hours
$29,609	Annual Energy Savings	$337,540
$11,000	Maintenace Savings	$125,400
$40,609	Energy + Maint. Savings	$462,940
Payback in Years	**1.6**	

150W PSMH vs. LED C w/controls		Assume an 11.4 year application life.
		Lifetime
91.4%	Energy Savings (%)	(X 11.4) 100K hours
$29,609	Annual Energy Savings	$337,540
$11,000	Maintenace Savings	$125,400
$40,609	Energy + Maint. Savings	$462,940
Payback in Years	**1.6**	

Annual Savings and Payback With Controls

	LED C With Controls
Initial Luminaire Cost	X + $30
Energy Savings	91%
Annual Energy Savings	$29,609
Maintenance Savings	$11,000
Annual Energy + Maintenance Savings	$40,609
Payback (in years)	1.6

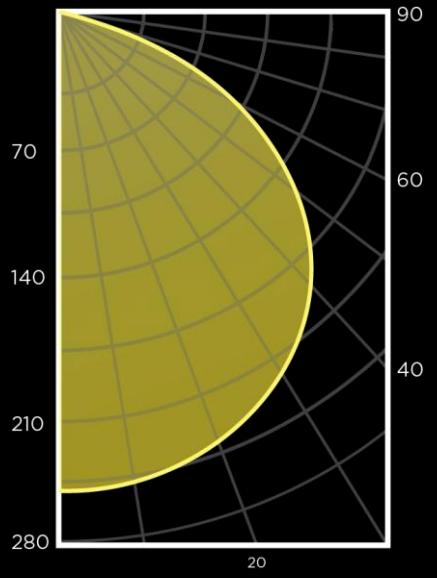
- Based on “low mode” 80% of the time and “high mode” 20% of the time.
  - High mode = 100% wattage & 100% output
  - Low mode = 15% wattage & >15% output

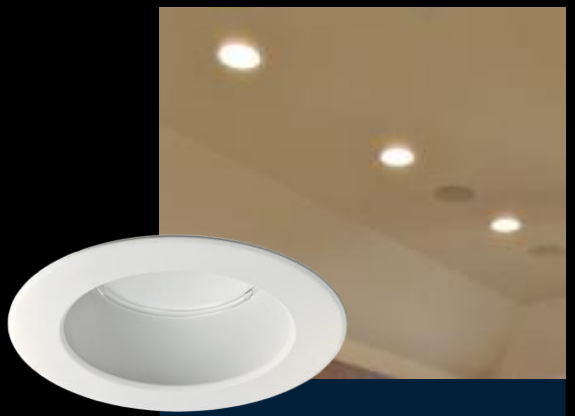
Sometimes the Evaluation Process Can be Simple

Example:
Direct Replacement LED Products

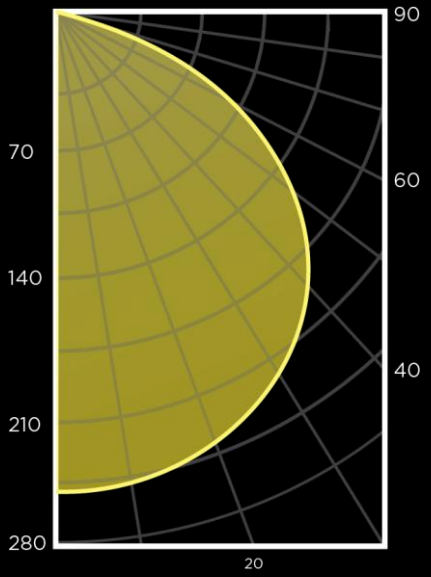
- Take the most popular downlight configuration…
- **Replicate** the aesthetics, output, color quality and light distribution…
- Improve the efficacy and eliminate all routine maintenance (i.e. relamping)

65W BR30 FL
CRI = 100

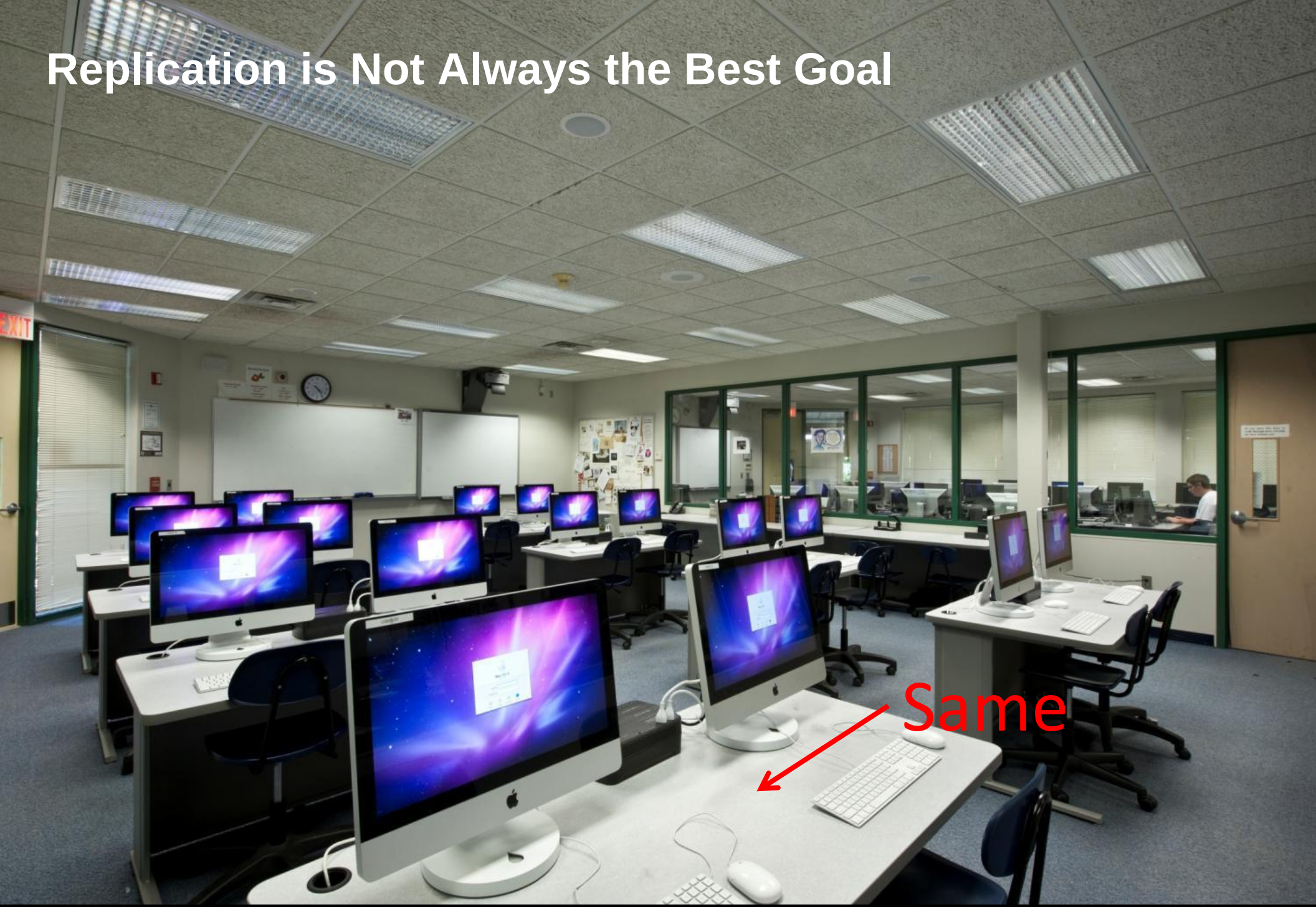




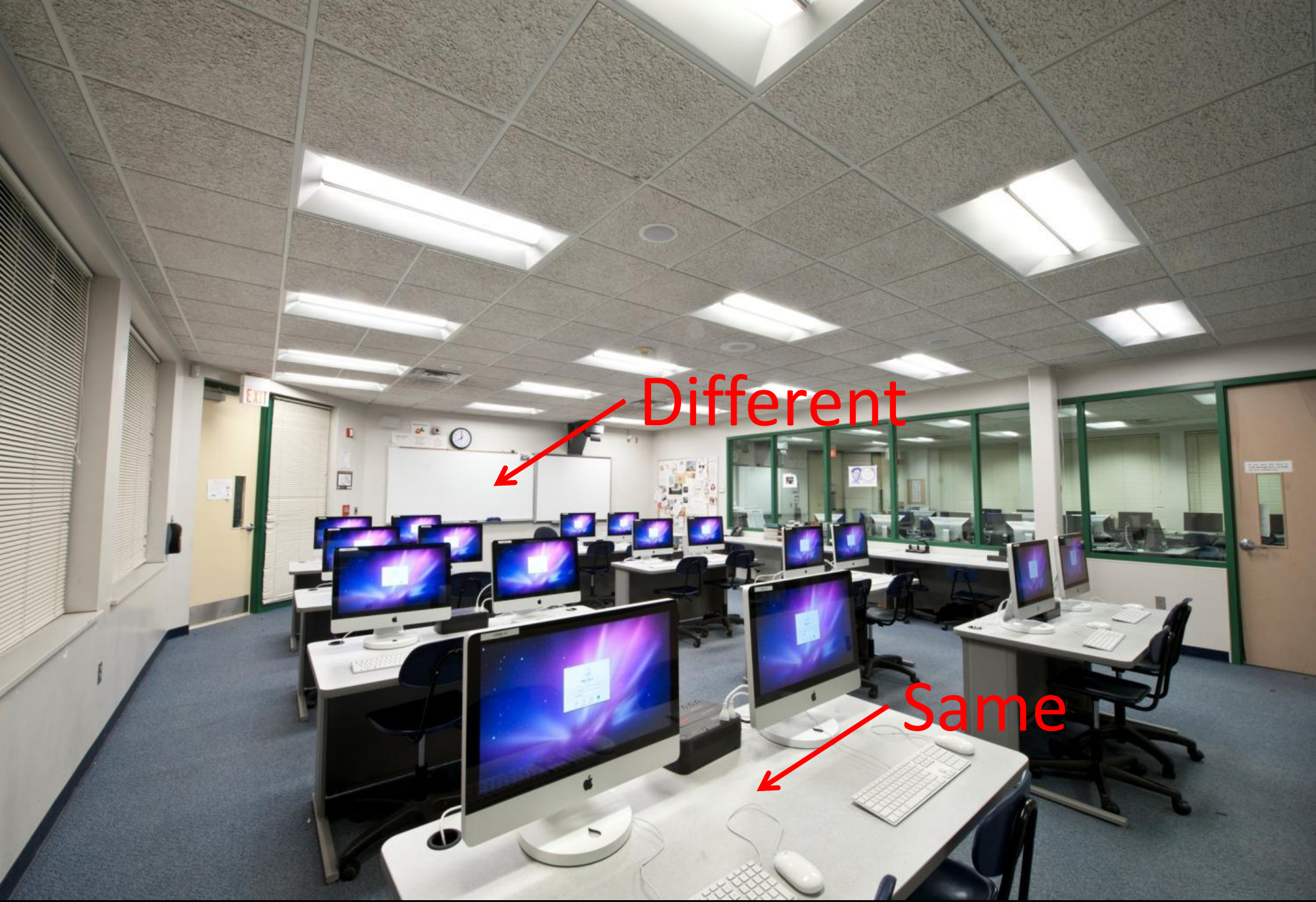
<10W
CRI = 92



Replication is Not Always the Best Goal



Computer Lab Before (2400W)



Computer Lab After (640W)

Retail Application – Case Study

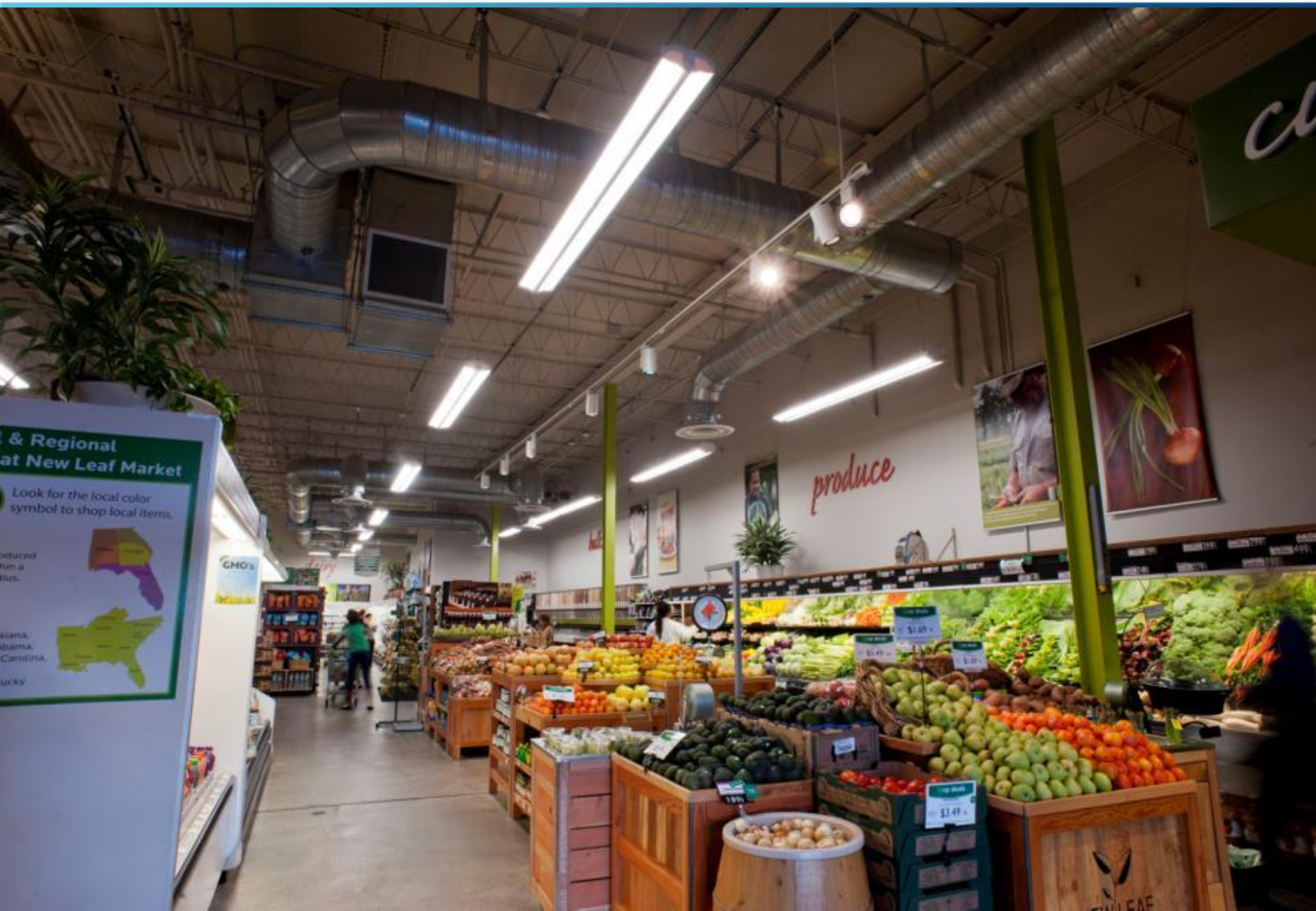
Grocery Retail (Before) 6 Lamp T8

Retail Application – Case Study

57% energy savings with broad spectrum color and great CRI

30fc maintained average illuminance

Retail Application – Case Study



Retail Application – Case Study

Project Fixture Options

The options for New Leaf Market to replace their original lighting systems included upgrading to Cree LED lighting or a fluorescent system more efficient than the original lighting.

Energy Comparison		Qty	Watts	Total Watts	Energy Savings
	Original Lighting 6-Lamp T8 Linear Fluor. (Direct/Indirect)	34	180	6,120	N/A
UPGRADE OPTIONS	**Cree LED Lighting** CS18 LED Linear Luminaire	38	70	2,660	57%
	Fluorescent Lighting 4-Lamp Energy Advantage T8 Linear Fluor. (Direct)	38	130	4,940	19%

> "Colors really pop now, with our new LED fixtures. The apples really do shine brighter. And the amount of additional light also has been impressive. Customers have commented on how much better things look, without even knowing why."
>
> **Larrane Hartridge**
> *General Manager, New Leaf Market*

Estimated Project Savings*

$28,155 Total Lifetime Savings

Up to 3,460 Total Watts Saved

$2,798 Avg. Annual Operating Savings

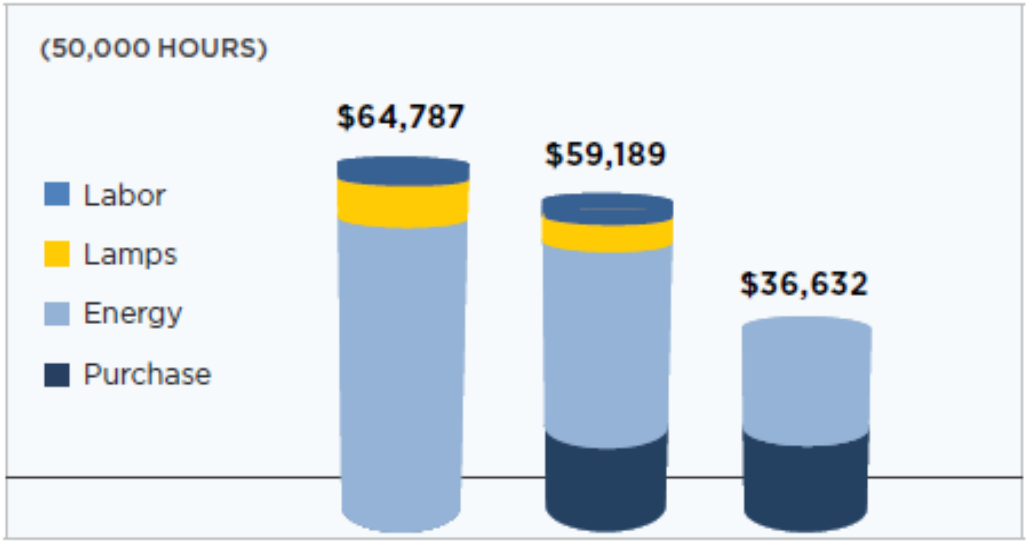
73 hrs. Saved Relamping (Lifetime)

Payback In Just over

8

MONTHS

Estimated Total Lifetime Costs*



*Savings and payback are representative of what consumers could expect operating in a typical grocery store environment using comparable products.

Retail Application – Case Study

Grocery - Upgrade

New Leaf Market

Tallahassee, FL

- Total lifetime savings of $28,155
- More than 3,400 watts saved; 57% energy savings
- Annual operating savings of $2,798

A commitment to sustainability in both its business and building practices led New Leaf Market to a Cree LED lighting solution. The Cree system not only dramatically improves the quality and reach of the market's lighting, it further advances a green initiative while adding some green to the bottom line.

SOLUTION

To that end, the cooperative turned to Cree for a more energy-efficient lighting solution, switching from linear fluorescents to Cree® CS18™ LED linear luminaires.

This improvement was immediately apparent to employees and customers alike. One of the market's stockers joked that his workload had just been increased because since everything looked so much better, the merchandise was going to fly off the shelf.

The improved light quality was also immediately evident to Robby Gilliom, Service Manager at Weston-Trawick, who recommended Cree to New Leaf Market. Robby installed the Cree LED fixtures for half the store in one night, with the fluorescents remaining in place in the other half, affording a clear comparison between the lighting options. According to Gilliom, the vivid "before and after" contrast was striking, with the Cree LED fixtures providing even light distribution all the way down to the bottom shelves. Additionally, the color quality of the products on the LED-lit side of the store was dramatically enhanced since the CS18™ LED linear luminaires feature a color rendering index (CRI) of 90. Gilliom also appreciated the ease of installing the lightweight fixtures since each row requires only one connection.

Illumination Quality Improvements

Metal Halide
19.1kW

LED
5.6kW

LED
850 Watts Per Pole

Metal Halide
3,070 Watts Per Pole

Energy Savings Breakdown

	EXISTING			PROPOSED		
	QTY	WATTS	TOTAL	QTY	WATTS	TOTAL
FRONTLINE	26	455	11830	13	851	11063
	26	1080	28080			
INTERIOR POLES	30	1080	32400	18	851	15318
PERIMETER SALES	16	1080	17280	8	851	6808
PERIMETER STORAGE	25	1080	27000	13	851	11063
WALL PACKS	12	288	3456	12	137	1644
GROUND LIGHTS	6	455	2730	4	137	548
				2	265	530
SOFFIT LIGHTS	15	210	3150	15	105	1575
TOTAL			125926			48549
ENERGY SAVINGS						61%

System Reliability Discussion

LED Package (Lamp) Failure Rates

- Assume 50 LEDs Per Luminaire
- Assume 50 ppm LED Package Failure
- Assume 3 or more LED failures in a fixture constitutes a failed product
  - Probability at 10,000 Hours = 1 in 1.25E-10
  - Probability at 25,000 Hours = 1 in 1.95E-9
  - Probability at 50,000 Hours = 1 in 1.56E-8 (1 in 156 Million)
  - Probability at 100,000 Hours = 1 in 1.25E-7

LED Driver Reliability???

Output Power
to LEDs

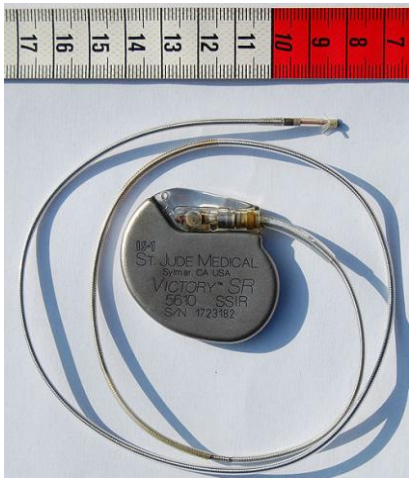
Input Power

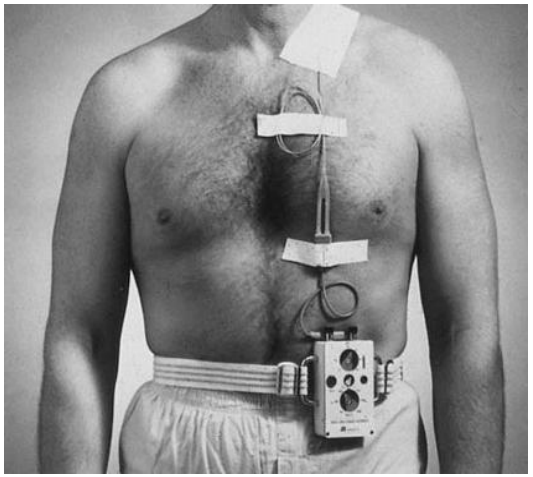
Do We Live in a World Where High Reliability Electronics Are a Assumed?

Engine Control Units (ECU) / Powertrain Control Units (PCM)

In 1958, Arne Larsson (1915–2001) became the first to receive an implantable pacemaker. He had a total of 26 devices during his life and campaigned for other patients needing pacemakers.

Heart Pacemakers





Non-Illumination Quality Related Reliability and Durability Performance

- Mechanical
  - Vibration Resistance
  - Corrosion Resistance
- Electrical
  - Driver Life and Reliability
  - Surge Protection
- Etc…

Vibration Resistance Testing

Types of Roadway Vibration

- Wind Induced (ground mounted)
- Traffic Induced (bridge / overpass mounted)

Examples of Relevant Testing and Standards

- ANSI C136.31-2001 Normal Applications Vibration Standards
- ANSI C136.31-2001 Bridge & Overpass Vibration Standards
- CALTrans (California Department of Transportation) 611 Vibration Testing

Surge Protection

IEEE/ANSI C62.41.2

- Different types of surge test wave forms are described for standard and special environments / difficult applications

- Peak voltages, peak currents, frequency and test duration are also factors defined in recommended test methods

- The MSSLC* Model Specification includes an Electrical Immunity Appendix D, that recommends three appropriate test specifications and related procedures for LED Roadway Luminaires
  - Test 1: Ring Wave
  - Test 2: Combination Wave
  - Test 3: Electrical Fast Test (EFT)

- Please refer to the MSSLC Model Specification for details

*Municipal Solid-state Streetlight Consortium

Salt Spray (Fog) Testing

A1

Magnification 3.4 Diameters

B1

Magnification 3.4 Diameters

Ensuring Performance and Energy Efficiency

The LED Promise

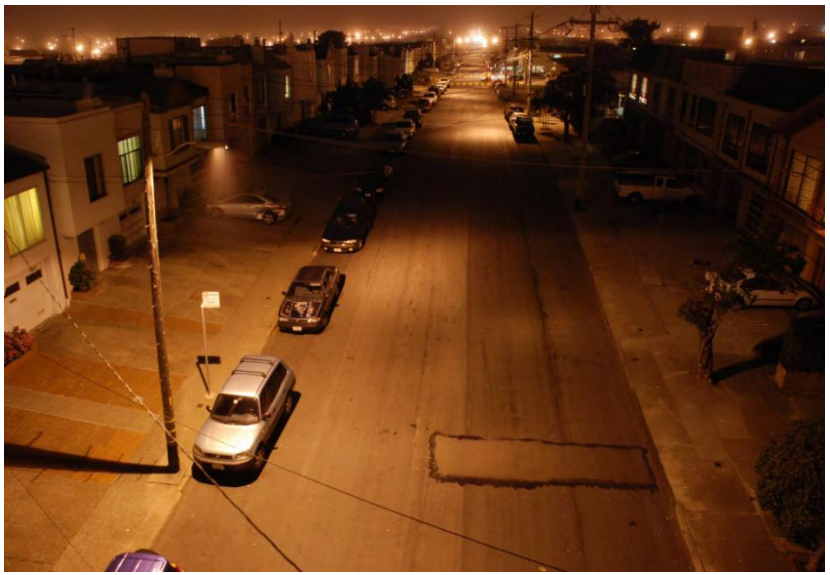
- ✓Better Lighting
- ✓Energy Savings
- ✓Longer Lifetimes
- ✓Less Maintenance
- ✓Control Options
- ✓Design Flexibility
- ✓… and more

Are these promises true?

How can efficiency programs distinguish quality products from the rest to assure market adoption?

The LED Lighting Market

- LEDs for general illumination hit the market in 2008
  - Demand takes off like a rocket!



- *High **Pressure** Sodium*

- *LED*

Learning Lessons from Past Mistakes

Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market

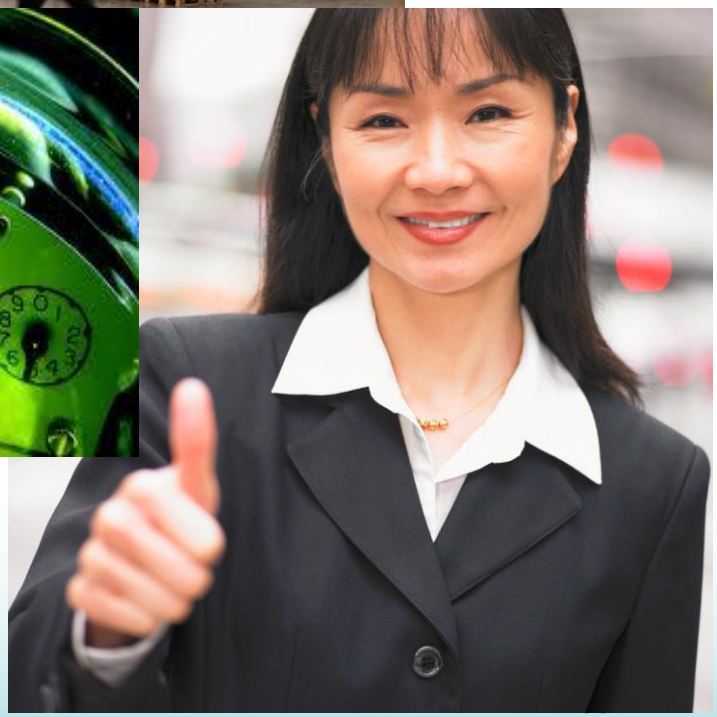
US DOE June 2006

- Quality & Performance sacrificed in rush to market
- CFL's Poor Reputation
- Loss of several years of savings
- Don't repeat this with SSL

DESIGNLIGHTS CONSORTIUM®

Critical Partnerships

- **Industry Players** invent, innovate, and bring technology to the marketplace
- **Efficiency Programs** promote quality and performance, provide financial rebates to overcome first cost, and educate customers
- **End Users** make wise buying choices




energy
ENERGY STAR


Municipal Solid-State
STREET LIGHTING
CONSORTIUM


LED Lighting Management
lighting
facts
LED Product Partner


DESIGNLIGHTS
CONSORTIUM

ENERGY STAR® for Solid State Lighting Products

ENERGY STAR

- Products that have earned the ENERGY STAR meet strict energy efficiency & performance guidelines set by the US EPA with open and broad stakeholder engagement
- ENERGY STAR products are available from more than 2,600 retailers in the US and Puerto Rico and are actively promoted by over 900 utilities
- ENERGY STAR is a trusted and recognized brand backed by third party certification & ongoing testing at accredited laboratories
- Influential brand recognized by more than 85% of Americans
- 92% of American's are influenced by the ENERGY STAR label when making purchasing decisions.

Product Eligibility

The following product types <u>are eligible</u> for ENERGY STAR

- **General purpose LED & Compact fluorescent lamps**
- ***Accent lights:** line-voltage directional track lights
- ***Down lights**: recessed, pendant, surface-mounted, solid state retrofit kits
- **Residential wall sconces, chandeliers, bath vanities, ceiling and close-to-ceiling mount**
- **Portable floor and table lamps**
- ***Portable desk task lights**
- ***Under cabinet/shelf-mounted task lighting**
- **Ceiling and ventilation fans with lighting**

**Residential/Commercial*

EPA

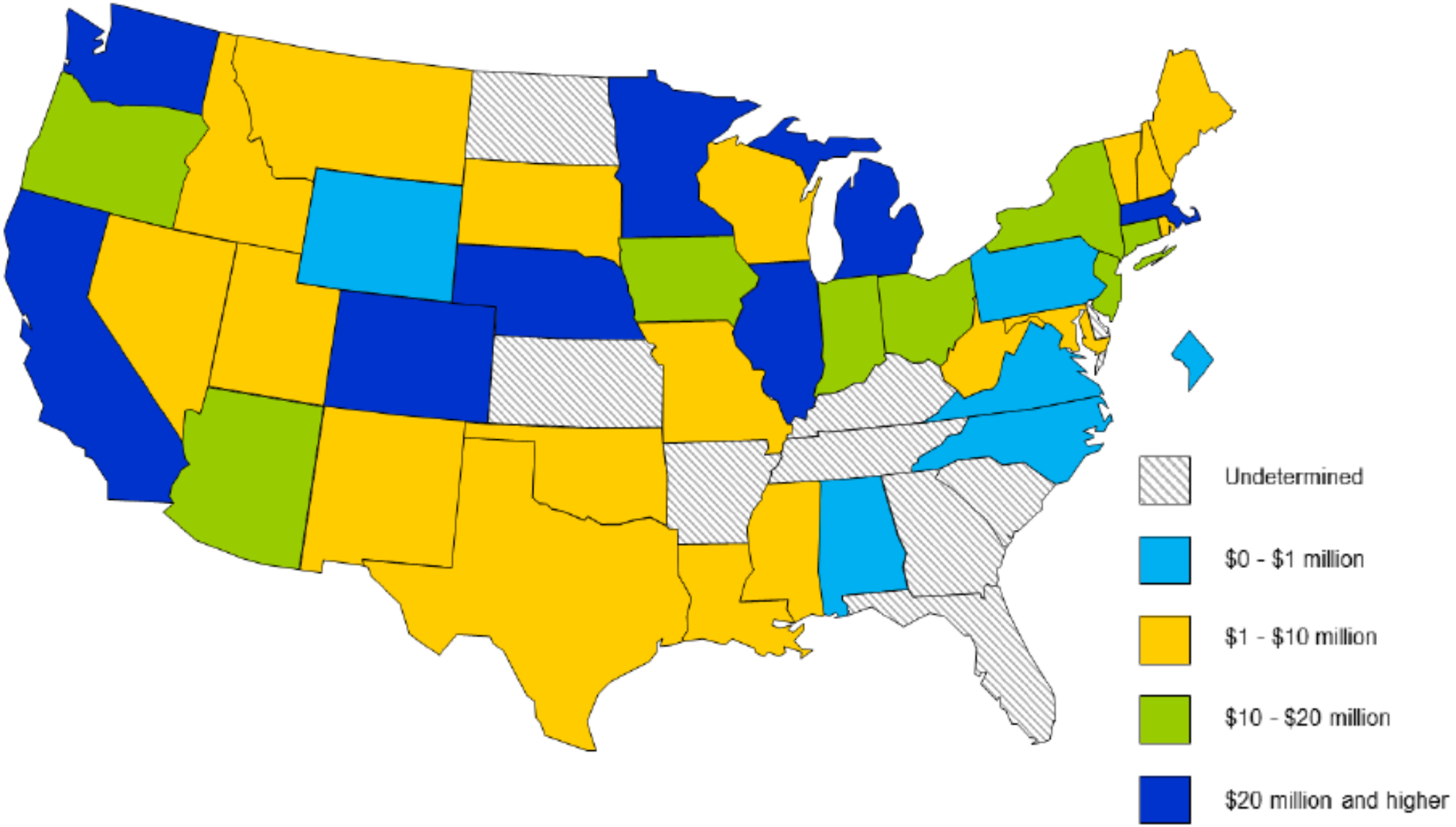
Product Eligibility

The following product types are <u>not eligible</u> for ENERGY STAR

- **Commercial street and area lights**
- **Wall packs**
- **Canopy**
- **High bays**
- **Recessed troffers**
- **General office illumination, adapters, or converters**
- **Theater lighting**

EPA

Utility Promotions for ENERGY STAR Lighting products



ENERGY STAR Summary of Lighting Programs, 8/2013

About The Consortium - Background

- Created by the U.S. Department of Energy (DOE) in March 2010 using American Recovery and Reinvestment Act (ARRA) funding
- Supported by the DOE GATEWAY program
- Intended to be an **educational resource** on Solid-State street lighting and associated technology for those involved in lighting streets and other outdoor public areas.
  - As an independent resource, the Consortium is available to help those unfamiliar with LED technology identify important issues and how to how to begin the evaluation process
- **…and** to help **accelerate adoption** of SSL technology in the nations street lighting systems

Municipal Solid-State STREET LIGHTING CONSORTIUM

Sponsored by the U.S. Department of Energy

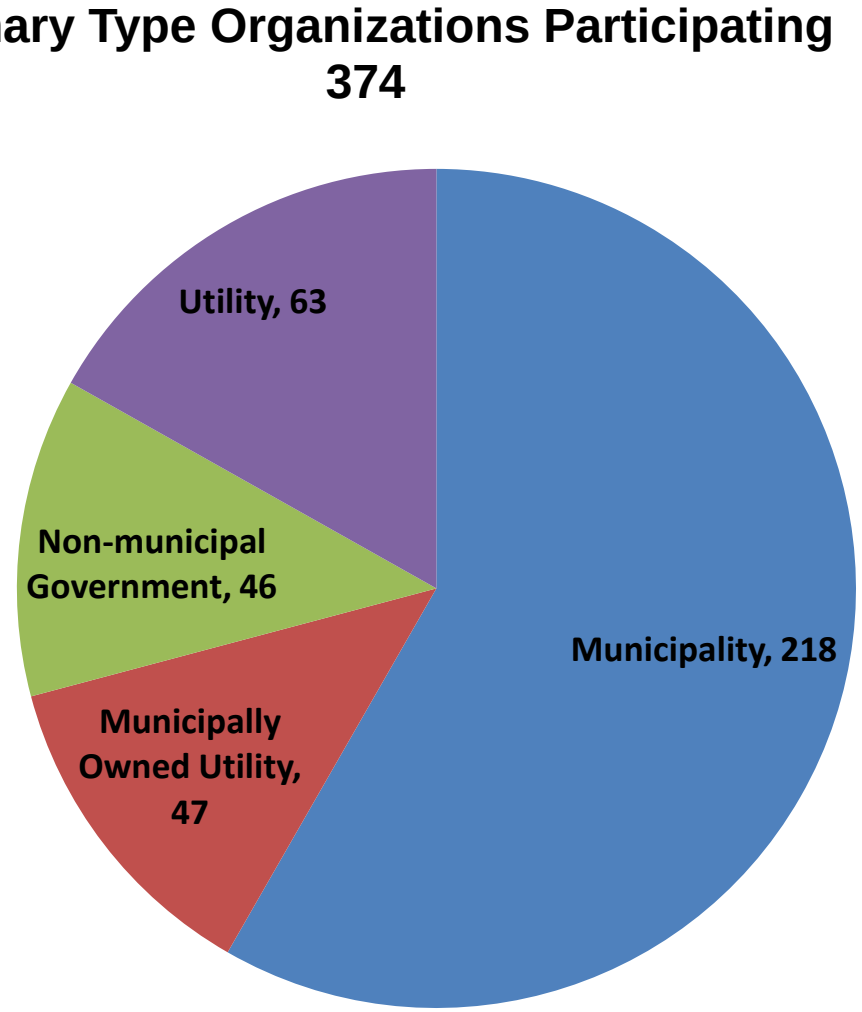
Our Vision

- Accelerate the adoption of high performance solid-state street and area lighting by leading end-user collaboration in the areas of performance, evaluation, application, and standardization.

Our Mission

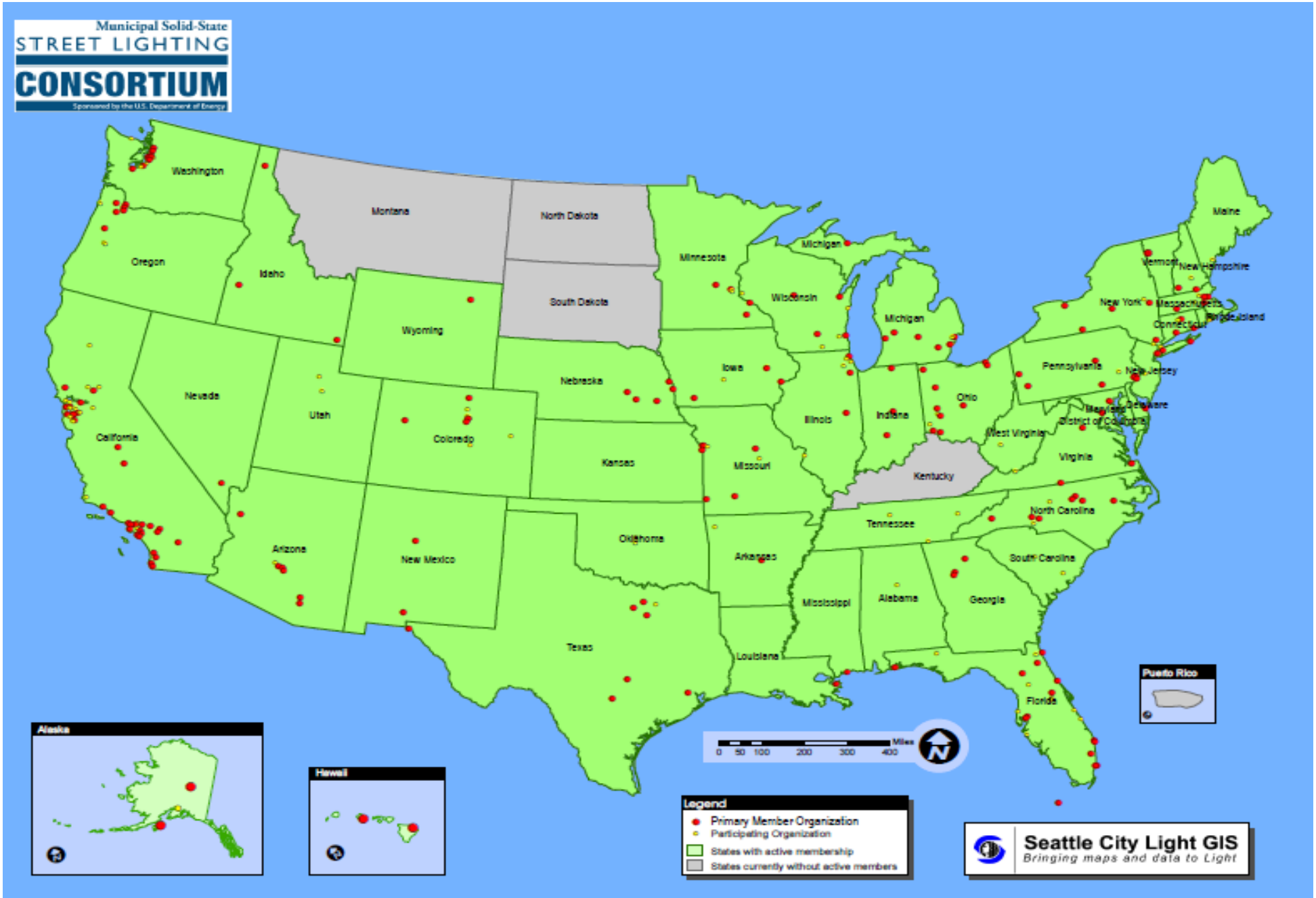
- Increase **KNOWLEDGE** around the performance, quality, and application of SS Street Lighting.
- Develop a national **STRUCTURE** to provide oversight and guidance on the evaluation of SSL for public areas.
- Influence national **STANDARDIZATION** of benchmarks, classification, design, and performance criteria. Set standard benchmarks.

Membership


Primary Type Organizations Participating
374
Utility, 63
Non-municipal Government, 46
Municipally Owned Utility, 47
Municipality, 218

Municipal Solid-State
STREET LIGHTING
CONSORTIUM

Sponsored by the U.S. Department of Energy



Municipal Solid-State STREET LIGHTING CONSORTIUM

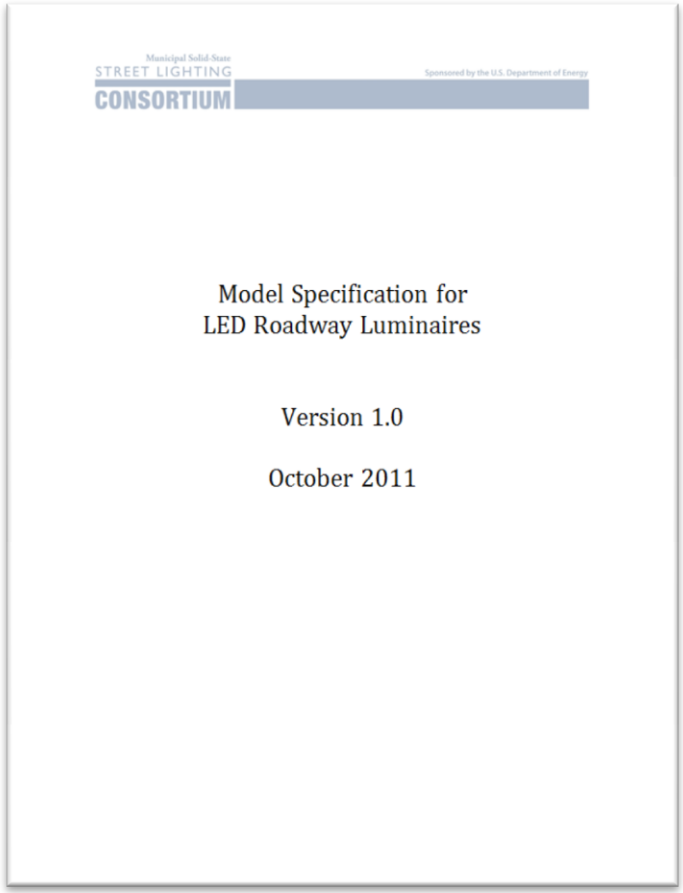
Sponsored by the U.S. Department of Energy

Resources Available

Model Specification for LED Roadway Luminaires

Scope

- Municipalities, utilities, large public spaces, etc.
- Streets, roadways, and nearby pedestrian ways
- Initial and maintained quality and quantity of illumination
- Warranty coverage
- Input power, electrical immunity, housing finish, vibration, etc.
- Drivers, including lighting controls interface
- Photocontrol receptacles



Download: http://www1.eere.energy.gov/buildings/ssl/specification.html

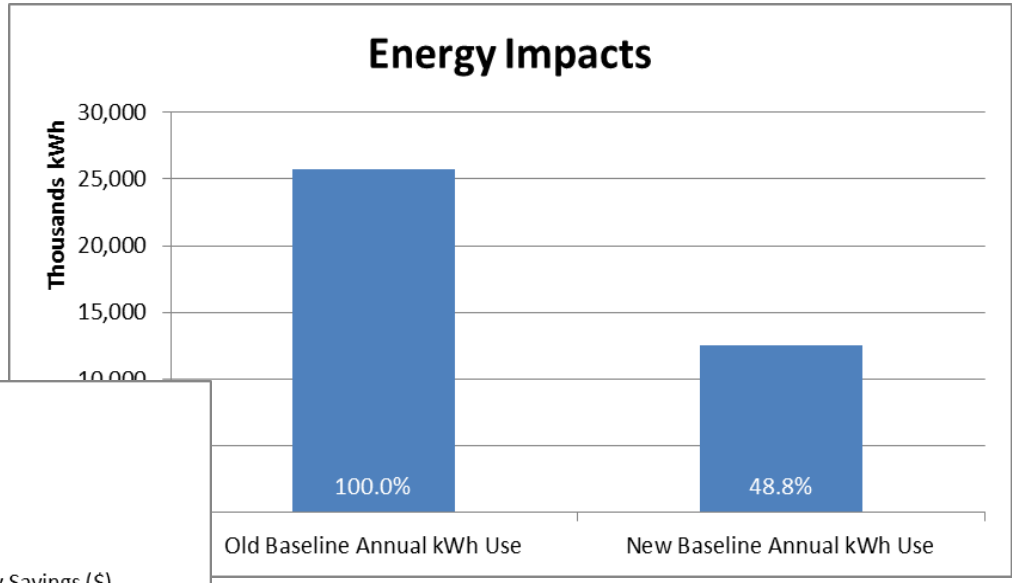
Municipal Solid-State STREET LIGHTING CONSORTIUM

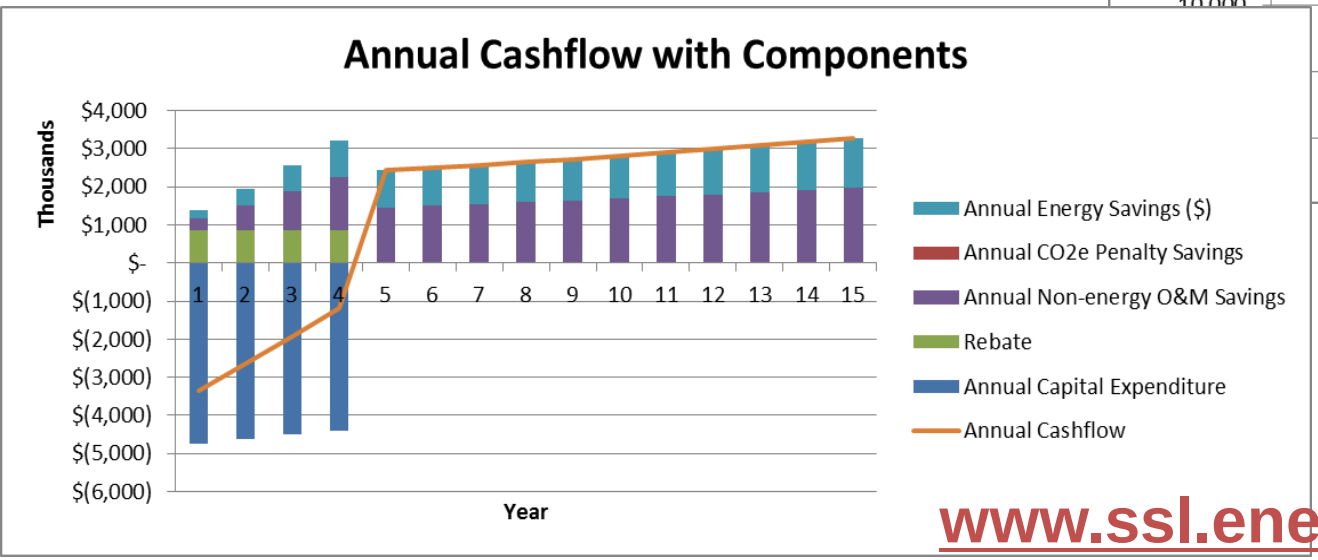
Sponsored by the U.S. Department of Energy

Resources – Financial Analysis Tool

Retrofit Financial Analysis Tool

- Evaluates costs and benefits of LED conversion
- Performs detailed analysis and provides numerous outputs, including:
  - Annual energy and energy-cost savings
  - Annual maintenance savings
  - Annual greenhouse gas reductions
  - Simple payback, IRR
  - Net present value





www.ssl.energy.gov/consortium.html

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

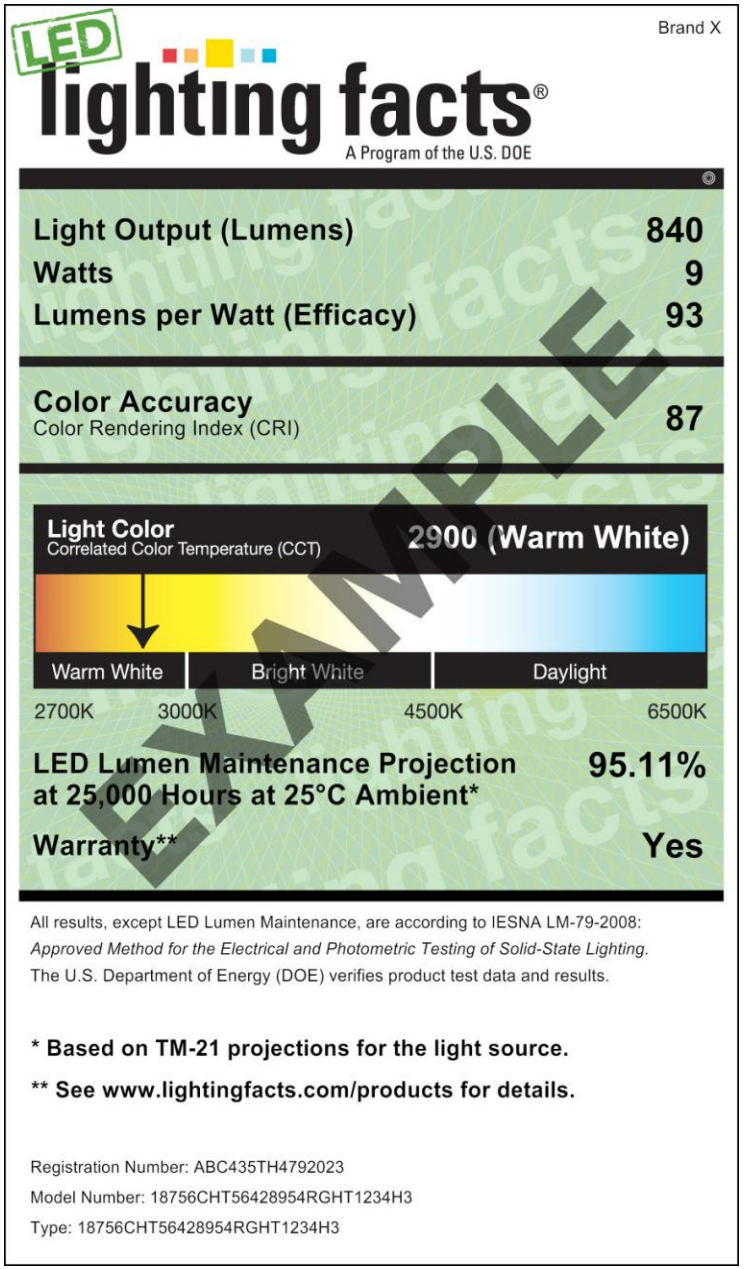
LED Lighting Facts®

LED lighting facts®

A Program of the U.S. DOE

LED Lighting Facts Overview

- Standardized summary of verifiable product performance data, measured by industry standards (LM-79, LM-80, TM-21)
- Web-based product performance reporting initiative
  - www.lightingfacts.com
- Industry tool to help buyers
  - Resource to evaluate reported product performance against manufacturer claims
- Label and product list backed by verification of performance testing
- A voluntary and free program

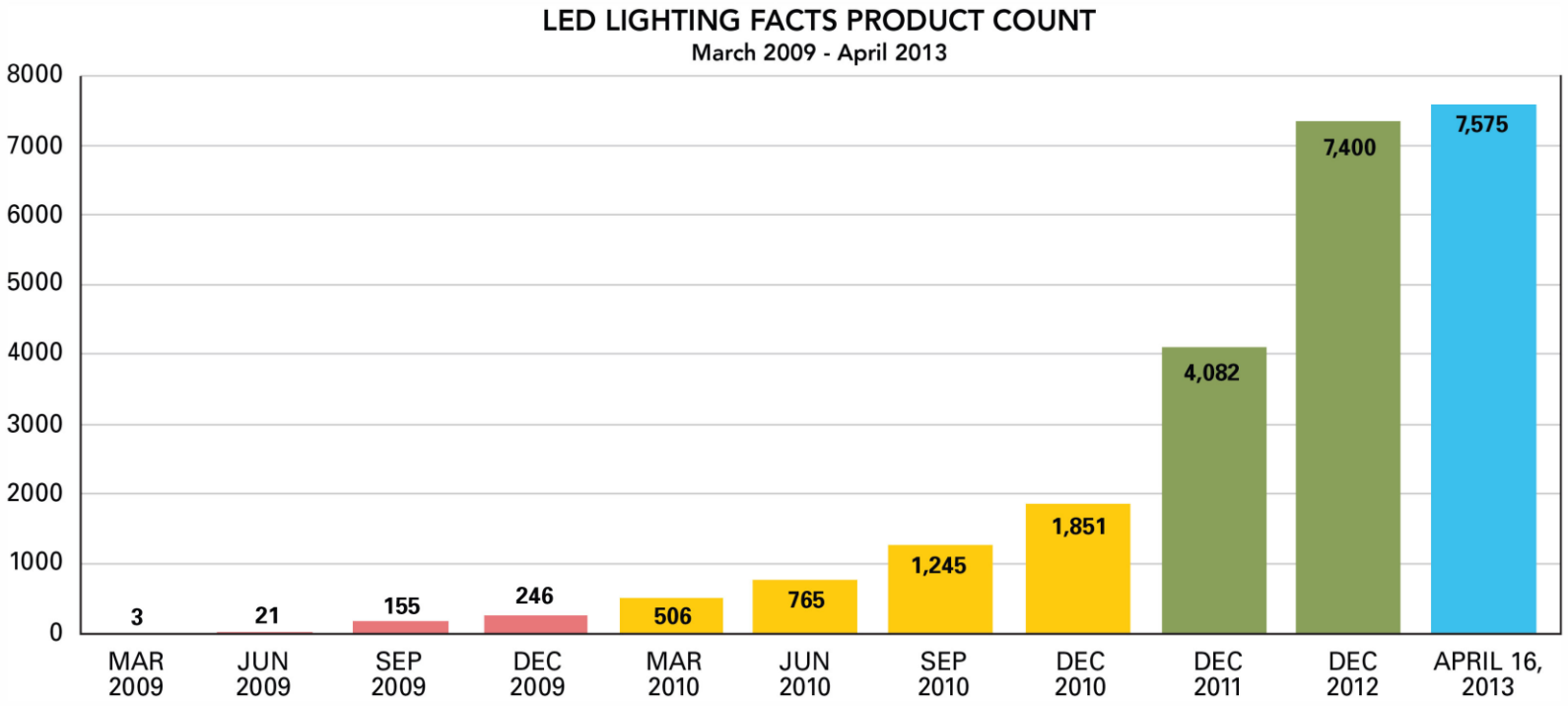


Increasing Participation and Value

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

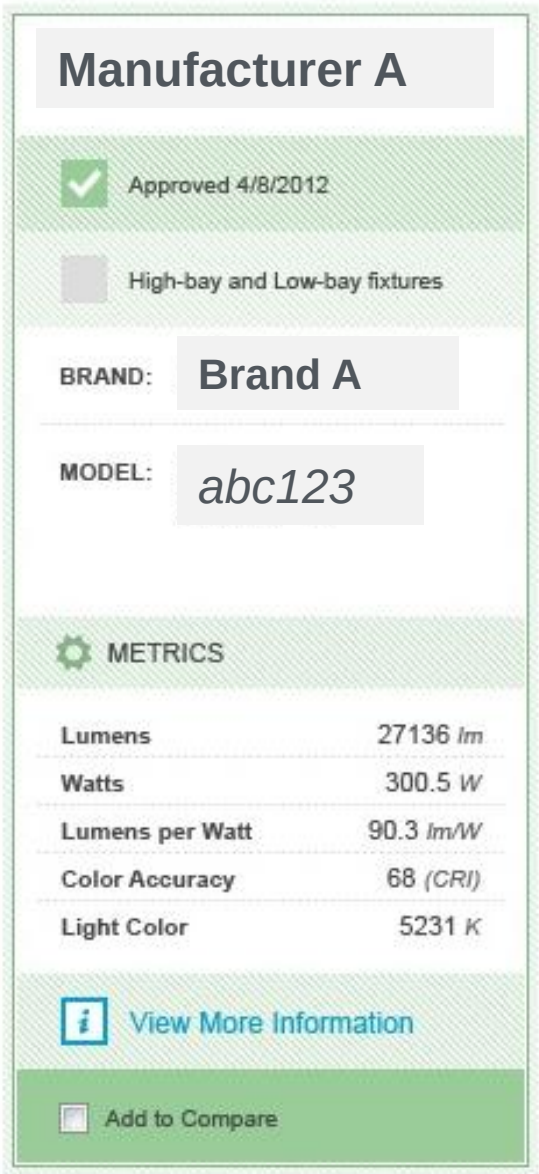
- SSL industry and LED Lighting Facts product list are growing
  - Over 500 products submitted each month

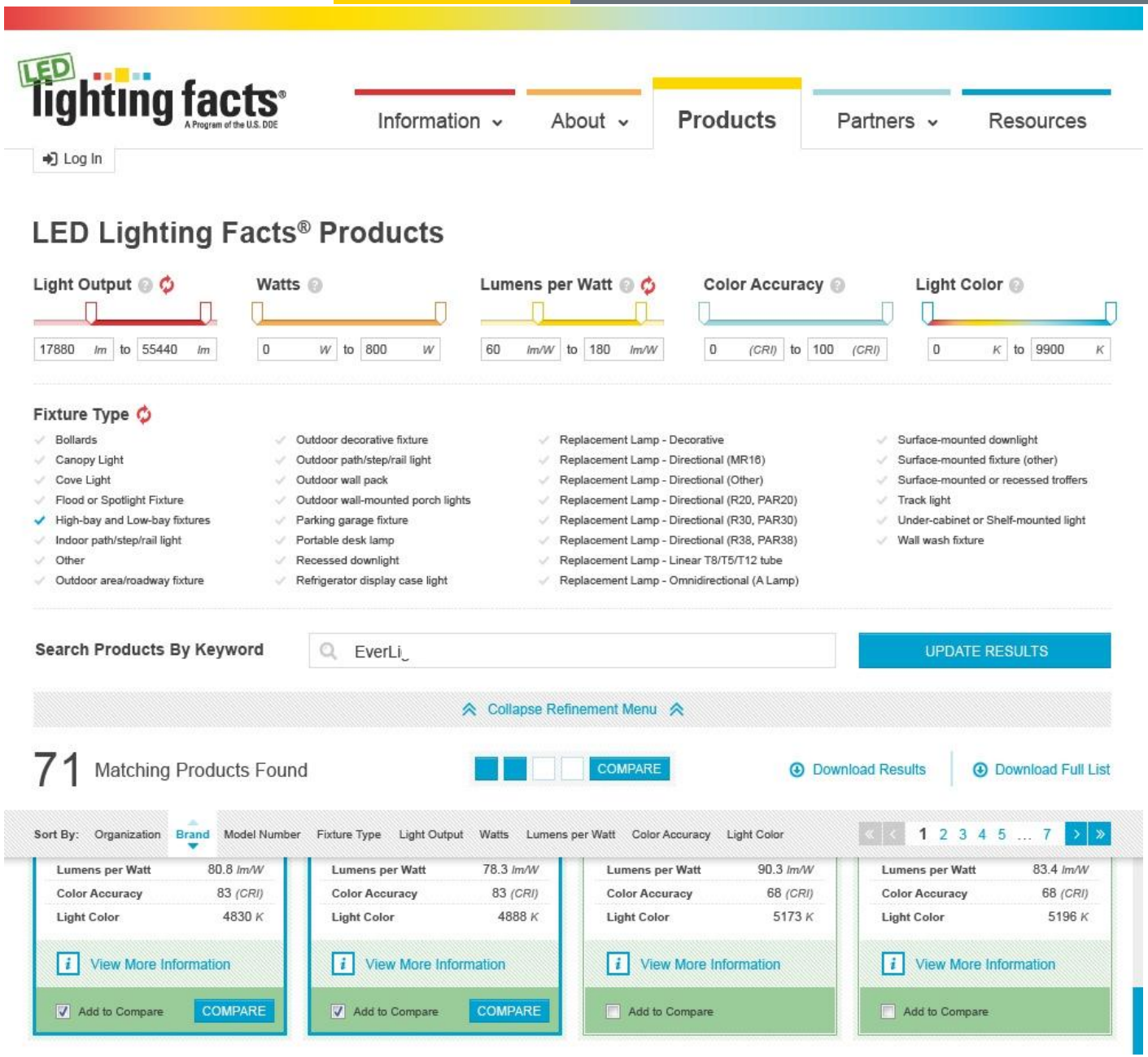
rely



* Over 1,000 products have been archived since annual product status update was implemented in November 2012.

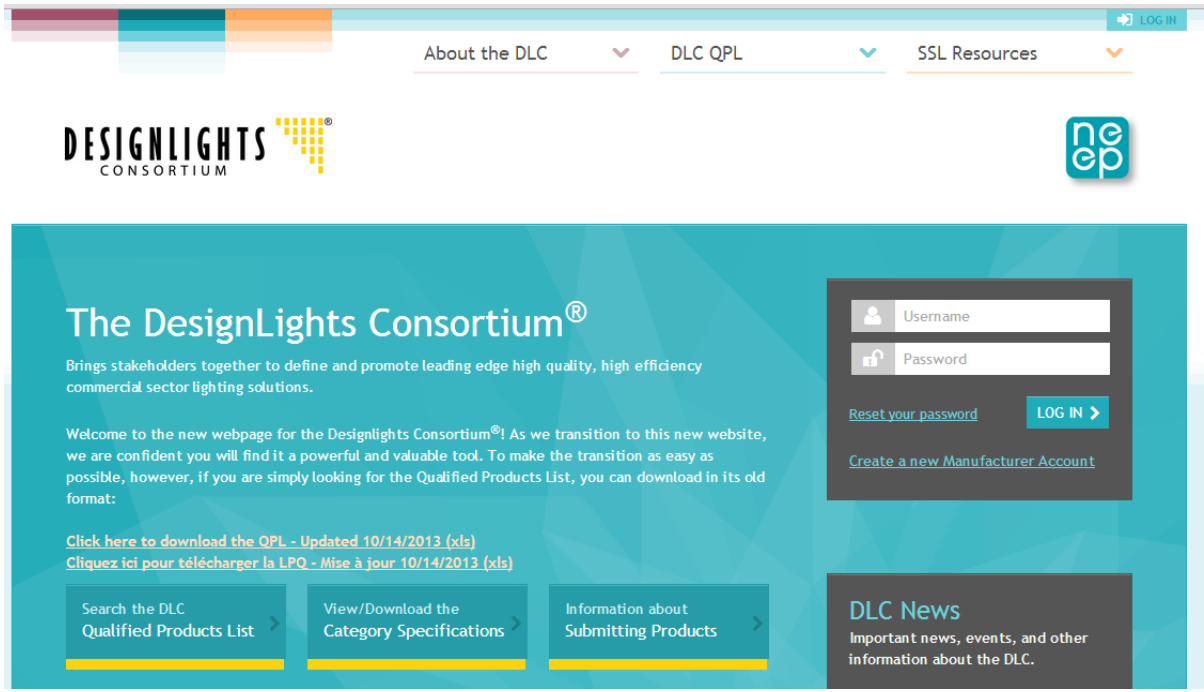
New Product Search!





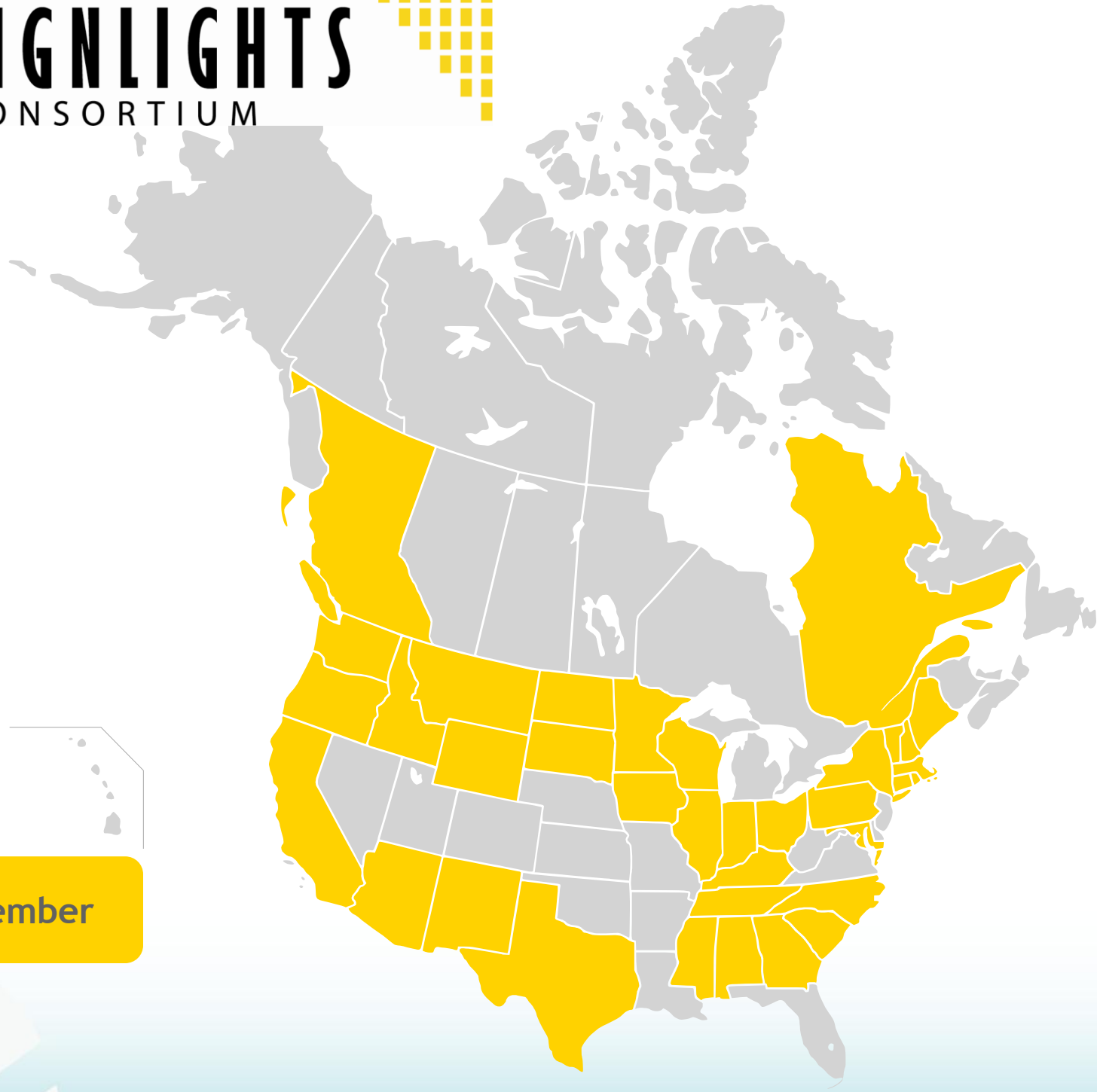
DesignLights Consortium®

- 1998: knowhow series
- 2006: HP T8 Project
- 2008: **DLC QPL**



www.designlights.org

DESIGNLIGHTS CONSORTIUM



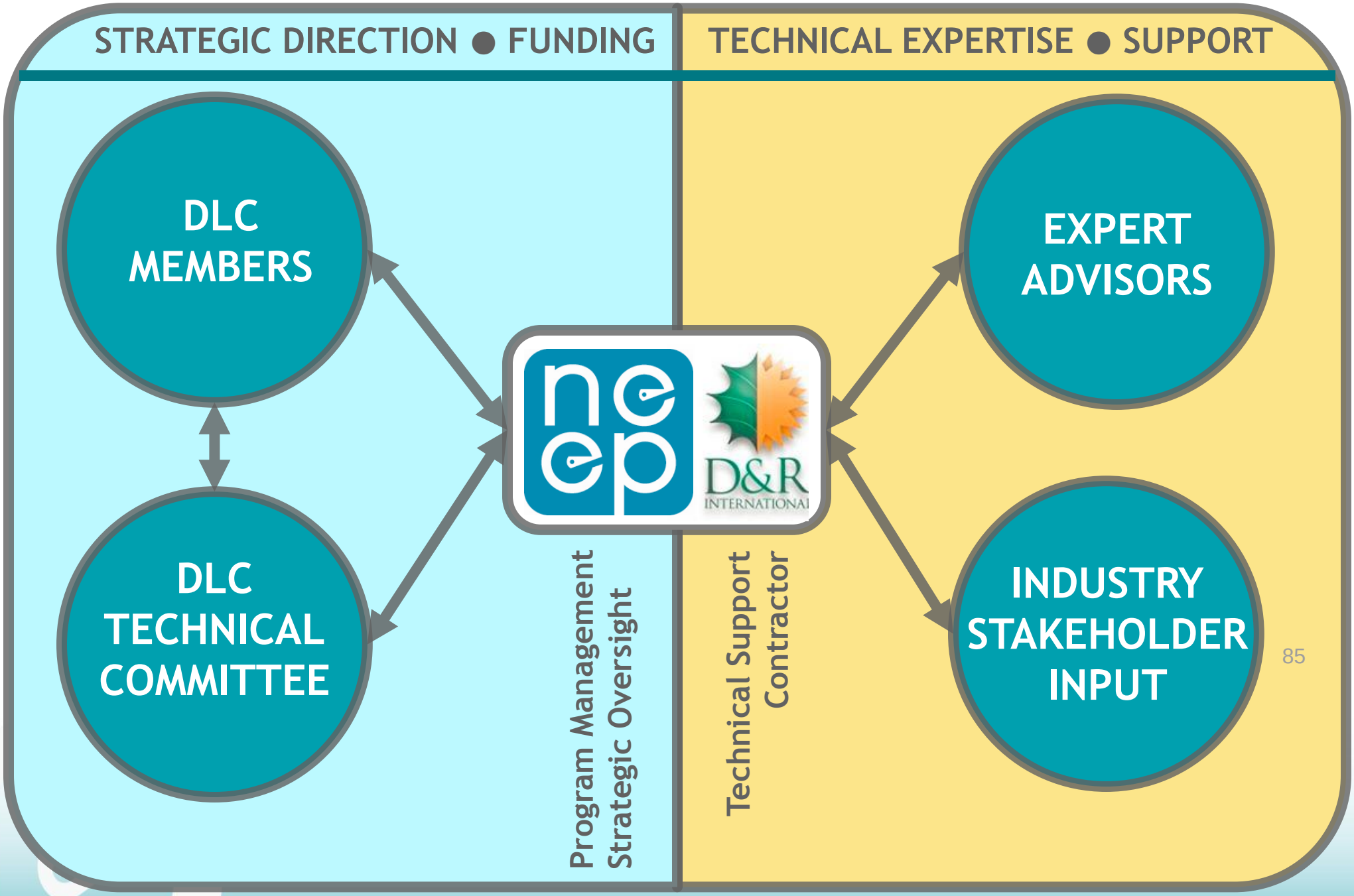
DLC Member

DLC Members


DESIGNLIGHTS CONSORTIUM
neep
Xcel Energy
SOUTHERN MINNESOTA MUNICIPAL POWER AGENCY
Bringing power to your life.
GEORGIA POWER
A SOUTHERN COMPANY
Connecticut Light & Power
A Northeast Utilities Company
FORTIS BC
Natural Resources Canada
EUMMOT
EFFICIENCY$MART
Western Massachusetts Electric
The Northeast Utilities System
nationalgrid
THE POWER OF ACTION
SMECO
Southern Maryland Electric Cooperative
SOUTHERN CALIFORNIA EDISON
an EDISON INTERNATIONAL Company
Ameren ILLINOIS
ComEd
Public Service of New Hampshire
Liberty Utilities
The United Illuminating Company
focus on energy
Partnering with Wisconsin utilities
BGE
MISSOURI RIVER ENERGY SERVICES
TACOMA POWER
TACOMA PUBLIC UTILITIES
neea
EnergyTrust of Oreg
DUKE ENERGY
SMUD
SACRAMENTO MUNICIPAL UTILITY DISTRICT
The Power To Do More.
Unitil
NSTAR
Hydro Québec
SDGE
A Sempra Energy utility
BONNEVILLE POWER ADMINISTRATION
WECC
wisconsin energy conservation corporation
PECO
An Exelon Company
NEW HAMPSHIRE Electric Co-op
SRP
Delivering more than power.
BURLINGTON Electric DEPARTMENT
nyserda
Energy. Innovation. Solutions.
PSE
PUGET SOUND ENERGY
MEEA
Midwest Energy Efficiency Alliance
BC hydro REGENERATION
LIPA
Long Island Power Authority
Seattle City Light
SNOHOMISH COUNTY PUD
PUBLIC UTILITY DISTRICT NO. 1
IDAHO POWER
An IDACORP Company
DCSEU
Cape Light Compact
SEEA
SOUTHEAST ENERGY EFFICIENCY ALLIANCE
Efficiency Vermont
TVA
PG&E
efficiency MAINE

DESIGNLIGHTS CONSORTIUM

DLC Structure



Technical Requirements Table v2.1

DesignLights Consortium® Product Qualification Criteria, *(FINAL 9/27/13)*

Technical Requirements Table, v2.1

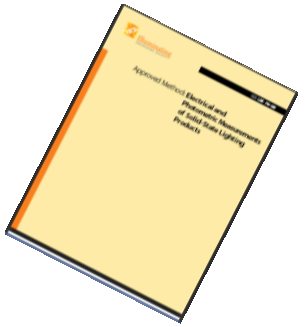
	Application Category	Minimum Light Output	Zonal Lumen Requirements	Minimum Luminaire Efficacy	Allowable CCTs (ANSI C78.377-2008)	Minimum CRI	L_{70} Lumen Maintenance	Minimum Luminaire Warranty
Outdoor Applications—New, Fully Integrated Luminaires								
1	Outdoor Pole/Arm-Mounted Area and Roadway Luminaires	1,000 lm	≈100%: 0-90° ≤10%: 80-90°	70 lm/W	≤5700K	65	50,000 hrs	5 years
2	Outdoor Pole/Arm-Mounted Decorative Luminaires	1,000 lm	≥65%: 0-90°	60 lm/W	≤5700K	65	50,000 hrs	5 years
3	Outdoor Wall-Mounted Area Luminaires	300 lm	≈100%: 0-90° ≤10%: 80-90°	70 lm/W	≤5700K	65	50,000 hrs	5 years
4	Bollards	500 lm	≤15%: 90-110° 0%: >110°	50 lm/W	≤5700K	65	50,000 hrs	5 years
5	Parking Garage Luminaires	2,000 lm	≥30%: 60-80° ≤25%: 70-80°	75 lm/W	≤5700K	65	50,000 hrs	5 years
6	Fuel Pump Canopy Luminaires	2,000 lm	≥40%: 0-40° ≥40%: 40-70°	80 lm/W	≤5700K	65	50,000 hrs	5 years
7	Landscape/Accent Flood and Spot Luminaires	250 lm (<1000 lm)	≥85% 0-90°	65 lm/W	≤5700K	65	50,000 hrs	5 years
8	Architectural Flood and Spot Luminaires	1000 lm	≥85% 0-90°	75 lm/W	≤5700K	65	50,000 hrs	5 years
9	Stairwell and Passageway Luminaires	750 lm	≥85% 0-90°***	75 lm/W	≤5700K	65	50,000 hrs	5 years
Indoor Applications—New, Fully Integrated Luminaires								
10	Wall-Wash Luminaires	575 lm	≥60%: 0-90°**	45 lm/W	≤5000K	80	50,000 hrs	5 years
11	Track or Mono-Point Directional	250 lm	≥85%: 0-90°	45 lm/W	≤5000K	80	50,000 hrs	5 years

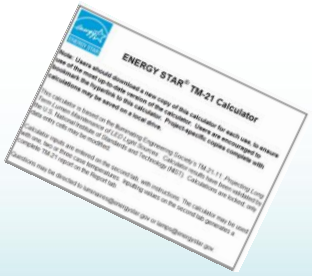
- **37 Categories**
  - Specs revised annually
  - New categories developed according to need and capacity
- **Multiple Parameters**
  1. Minimum Light Output
  2. Zonal Lumens/Light Distribution
  3. Minimum Efficacy
  4. CCT
  5. CRI
  6. L_{70} Lumen Maintenance
  7. THD and Power Factor
  8. Warranty

QPL: Manufacturer Application

Testing & Reporting Requirements

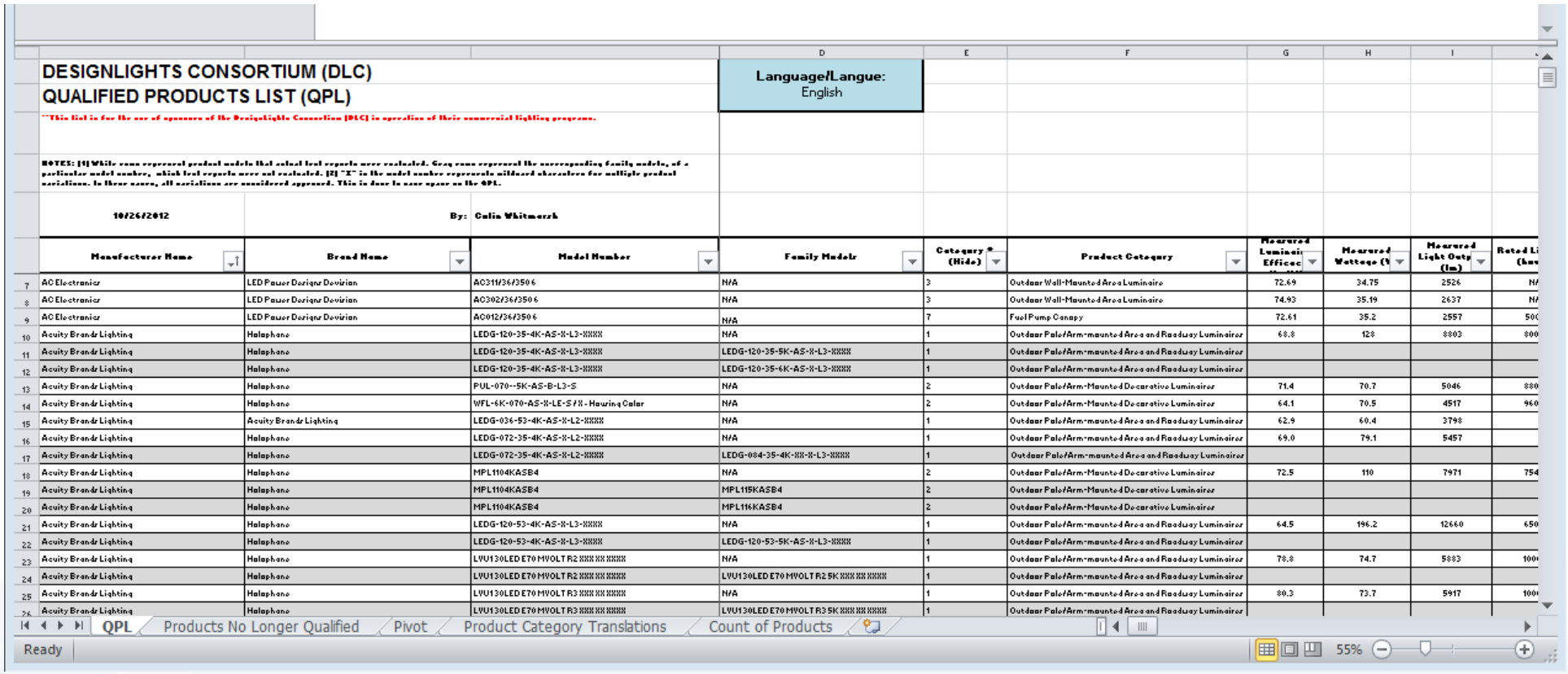
- Photometric & Electric Properties
  - IES LM-79-08 Electric & Photometric
    - Output & color: Integrating Sphere
    - Light Distribution: Goniophotometer
- Lumen Maintenance
  - Light Package Testing
    - IES LM-80-08 Lumen Maintenance
  - Luminaire-level Testing
    - ISTMT (ANSI/UL 1598-04)
  - L_{70} Determination
    - IES TM-21-11 Projecting Lumen Maintenance





DLC Qualified Products List

Download-able Workbook



DESIGNLIGHTS CONSORTIUM (DLC)
QUALIFIED PRODUCTS LIST (QPL)

Language/Langue: English

"This list is for the use of sponsors of the DesignLights Consortium (DLC) in operation of their commercial lighting programs.

NOTES: [1] While some represented product models that submit test reports were evaluated. Grey rows represent the corresponding family models, of a particular model number, which test reports were not evaluated. [2] "X" in the model number represents wildcard characters for multiple product variations. In these cases, all variations are considered approved. This is done to save space on the QPL.

10/26/2012 By: Colin Whitmarsh

Manufacturer Name	Brand Name	Model Number	Family Models	Category # (Hide)	Product Category	Measured Luminaire Efficac	Measured Wattage (W	Measured Light Outp (lm)	Rated Li (hou
AC Electronics	LED Power Designs Division	AC311/36/3506	N/A	3	Outdoor Wall-Mounted Area Luminaire	72.69	34.75	2526	NA
AC Electronics	LED Power Designs Division	AC302/36/3506	N/A	3	Outdoor Wall-Mounted Area Luminaire	74.93	35.19	2637	NA
AC Electronics	LED Power Designs Division	AC012/36/3506	N/A	7	Fuel Pump Canopy	72.61	35.2	2557	500
Acuity Brands Lighting	Holophane	LEDG-120-35-4K-AS-X-L3-XXXX	N/A	1	Outdoor Pole/Arm-mounted Area and Roadway Luminaires	68.8	128	8803	800
Acuity Brands Lighting	Holophane	LEDG-120-35-4K-AS-X-L3-XXXX	LEDG-120-35-5K-AS-X-L3-XXXX	1	Outdoor Pole/Arm-mounted Area and Roadway Luminaires				
Acuity Brands Lighting	Holophane	LEDG-120-35-4K-AS-X-L3-XXXX	LEDG-120-35-6K-AS-X-L3-XXXX	1	Outdoor Pole/Arm-mounted Area and Roadway Luminaires				
Acuity Brands Lighting	Holophane	PUL-070--5K-AS-B-L3-S	N/A	2	Outdoor Pole/Arm-Mounted Decorative Luminaires	71.4	70.7	5046	880
Acuity Brands Lighting	Holophane	WFL-6K-070-AS-X-LE-S/X - Housing Color	N/A	2	Outdoor Pole/Arm-Mounted Decorative Luminaires	64.1	70.5	4517	960
Acuity Brands Lighting	Acuity Brands Lighting	LEDG-036-53-4K-AS-X-L2-XXXX	N/A	1	Outdoor Pole/Arm-mounted Area and Roadway Luminaires	62.9	60.4	3798	
Acuity Brands Lighting	Holophane	LEDG-072-35-4K-AS-X-L2-XXXX	N/A	1	Outdoor Pole/Arm-mounted Area and Roadway Luminaires	69.0	79.1	5457	
Acuity Brands Lighting	Holophane	LEDG-072-35-4K-AS-X-L2-XXXX	LEDG-084-35-4K-XX-X-L3-XXXX	1	Outdoor Pole/Arm-mounted Area and Roadway Luminaires				
Acuity Brands Lighting	Holophane	MPL1104KASB4	N/A	2	Outdoor Pole/Arm-Mounted Decorative Luminaires	72.5	110	7971	754
Acuity Brands Lighting	Holophane	MPL1104KASB4	MPL115KASB4	2	Outdoor Pole/Arm-Mounted Decorative Luminaires				
Acuity Brands Lighting	Holophane	MPL1104KASB4	MPL116KASB4	2	Outdoor Pole/Arm-Mounted Decorative Luminaires				
Acuity Brands Lighting	Holophane	LEDG-120-53-4K-AS-X-L3-XXXX	N/A	1	Outdoor Pole/Arm-mounted Area and Roadway Luminaires	64.5	196.2	12660	650
Acuity Brands Lighting	Holophane	LEDG-120-53-4K-AS-X-L3-XXXX	LEDG-120-53-5K-AS-X-L3-XXXX	1	Outdoor Pole/Arm-mounted Area and Roadway Luminaires				
Acuity Brands Lighting	Holophane	LVU130LED E70 MVOLT R2 XXX XX XXXX	N/A	1	Outdoor Pole/Arm-mounted Area and Roadway Luminaires	78.8	74.7	5883	100
Acuity Brands Lighting	Holophane	LVU130LED E70 MVOLT R2 XXX XX XXXX	LVU130LED E70 MVOLT R2 5K XXX XX XXXX	1	Outdoor Pole/Arm-mounted Area and Roadway Luminaires				
Acuity Brands Lighting	Holophane	LVU130LED E70 MVOLT R3 XXX XX XXXX	N/A	1	Outdoor Pole/Arm-mounted Area and Roadway Luminaires	80.3	73.7	5917	100
Acuity Brands Lighting	Holophane	LVU130LED E70 MVOLT R3 XXX XX XXXX	LVU130LED E70 MVOLT R3 5K XXX XX XXXX	1	Outdoor Pole/Arm-mounted Area and Roadway Luminaires				

QPL | Products No Longer Qualified | Pivot | Product Category Translations | Count of Products

Ready 55%

DESIGNLIGHTS CONSORTIUM®

DLC Qualified Products List

New Search & Sort

Reset Search

Voir en Français

Define Your QPL Search

Include De-Listed Products

The DLC QPL search allows you to find the results you really need. Just choose your criteria from the available categories below, then click 'search' to run your query.

Click Here to view the whole, unfiltered list

27,888
RESULTS FOUND

Done defining your criteria? Click 'search' to see your results.

Search

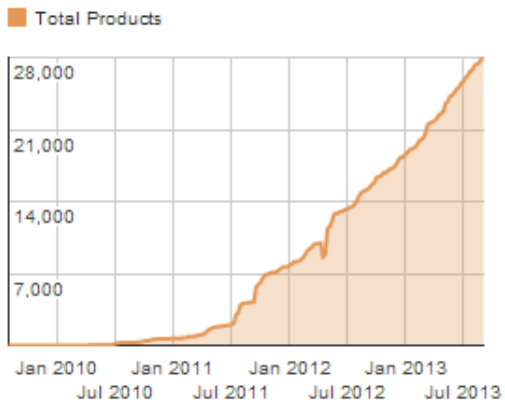
Search by Keyword i.e. Model Number, Brand Name, etc.

Measured Criteria

Light Output	Between	14	and	82893	lm
Efficacy	Between	31	and	132	lm/W
Wattage	Between	2	and	932	W
CRI	Between	52	and	97	

QPL Summary Data

Total Products by Year



Total Products by Category

Categories	Total
1x4 Luminaires for Ambient Lighting of Interior Commercial Spaces	320
2x2 Luminaires for Ambient Lighting of Interior Commercial Spaces	585
2x4 Luminaires for Ambient Lighting of Interior Commercial Spaces	479

Technical Requirements Table v2.1

- **Multiple Parameters**
  1. Minimum Light Output
  2. Zonal Lumens/Light Distribution
  3. Minimum Efficacy
  4. CCT
  5. CRI
  6. L_{70} Lumen Maintenance
  7. THD and Power Factor
  8. Warranty

Technical Requirements Table v2.1

- **Multiple Parameters**
  1. Minimum Light Output
  2. Zonal Lumens/Light Distribution
  3. Minimum Efficacy
  4. CCT
  5. CRI
  6. L_{70} Lumen Maintenance
  7. THD and Power Factor
  8. Warranty

Minimum Light Output

LM-79

Originally benchmarked to incumbent technology

Specification evolved to allow for design flexibility

- One-for-one replacements
- Designed installations

Technical Requirements Table v2.1

- **Multiple Parameters**
  1. Minimum Light Output
  2. Zonal Lumens/Light Distribution
  3. Minimum Efficacy
  4. CCT
  5. CRI
  6. L_{70} Lumen Maintenance
  7. THD and Power Factor
  8. Warranty

Light Distribution

LM-79
Zonal Lumens
Spacing Criteria

Originally benchmarked to incumbent technology

Specification evolved to address

- Market availability
- Attributes of LED

Technical Requirements Table v2.1

- **Multiple Parameters**
  1. Minimum Light Output
  2. Zonal Lumens/Light Distribution
  3. Minimum Efficacy
  4. CCT
  5. CRI
  6. L_{70} Lumen Maintenance
  7. THD and Power Factor
  8. Warranty

Minimum Efficacy

LM-79

Originally benchmarked to incumbent technology

Specification evolved to take advantage of market developments

Technical Requirements Table v2.1

- **Multiple Parameters**
  1. Minimum Light Output
  2. Zonal Lumens/Light Distribution
  3. Minimum Efficacy
  4. CCT
  5. CRI
  6. L_{70} Lumen Maintenance
  7. THD and Power Factor
  8. Warranty

Color

LM-79

Originally benchmarked to incumbent technology

Specification evolved in response to market developments and consumer demand

DLC aligns
- Indoor products: ≤5000 K
- Outdoor products: ≤5700 K

Technical Requirements Table v2.1

- **Multiple Parameters**
  1. Minimum Light Output
  2. Zonal Lumens/Light Distribution
  3. Minimum Efficacy
  4. CCT
  5. CRI
  6. L_{70} Lumen Maintenance
  7. THD and Power Factor
  8. Warranty

Lumen Maintenance

LM-80, ISTMT, TM-21

Not intended as lifetime metric

Number of hours to decay to 70% of initial output

DLC requires 50,000 hours for most categories

Technical Requirements Table v2.1

- **Multiple Parameters**
  1. Minimum Light Output
  2. Zonal Lumens/Light Distribution
  3. Minimum Efficacy
  4. CCT
  5. CRI
  6. L_{70} Lumen Maintenance
  7. THD and Power Factor
  8. Warranty

Power Quality

LM-79

Power Factor: Ratio of power performing the load to the apparent power in the circuit
DLC spec: ≤0.9

Total Harmonic Distortion: ratio of all harmonic components to the fundamental frequency
DLC spec: ≤20%

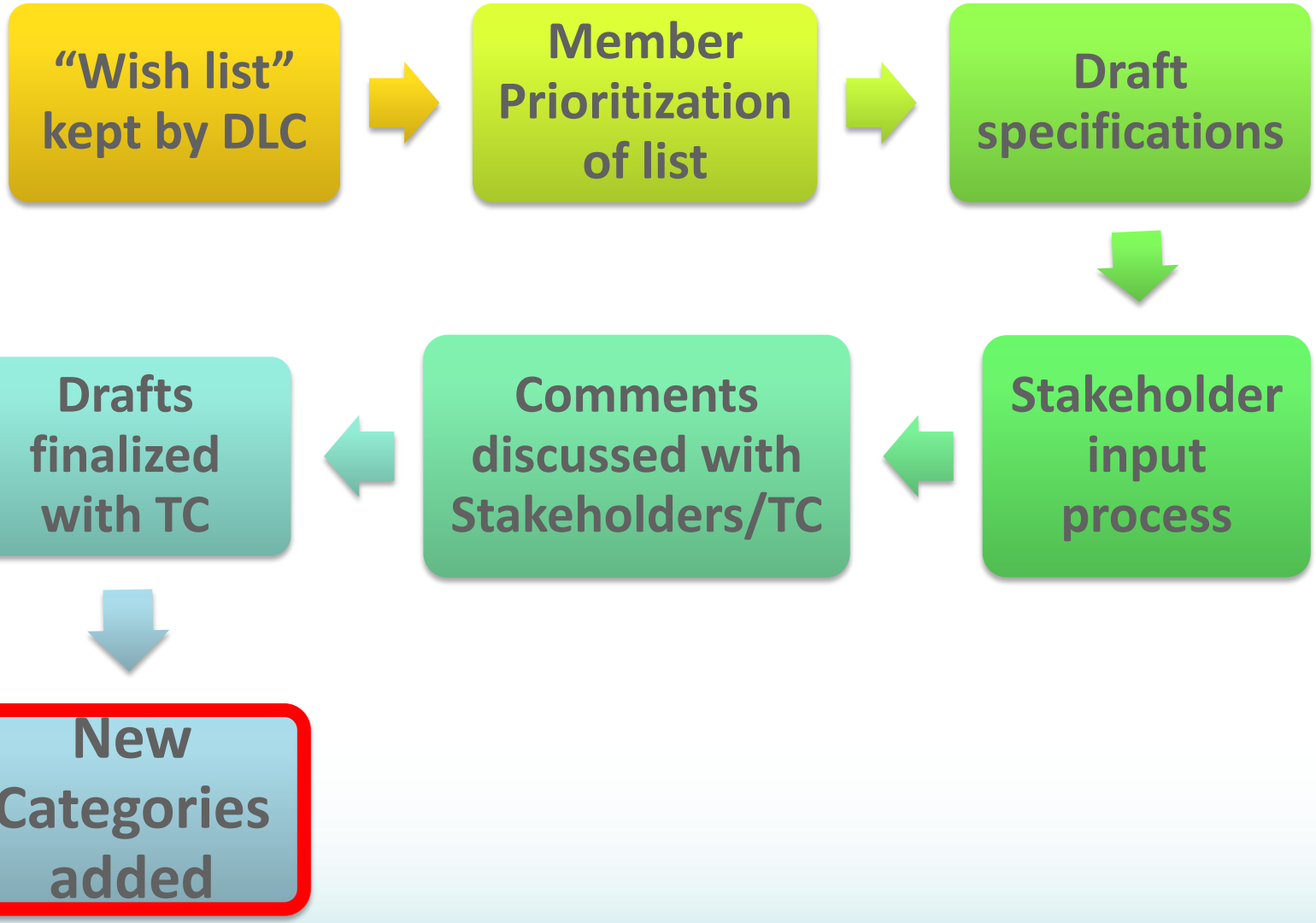
Technical Requirements Table v2.1

- **Multiple Parameters**
  1. Minimum Light Output
  2. Zonal Lumens/Light Distribution
  3. Minimum Efficacy
  4. CCT
  5. CRI
  6. L_{70} Lumen Maintenance
  7. THD and Power Factor
  8. Warranty

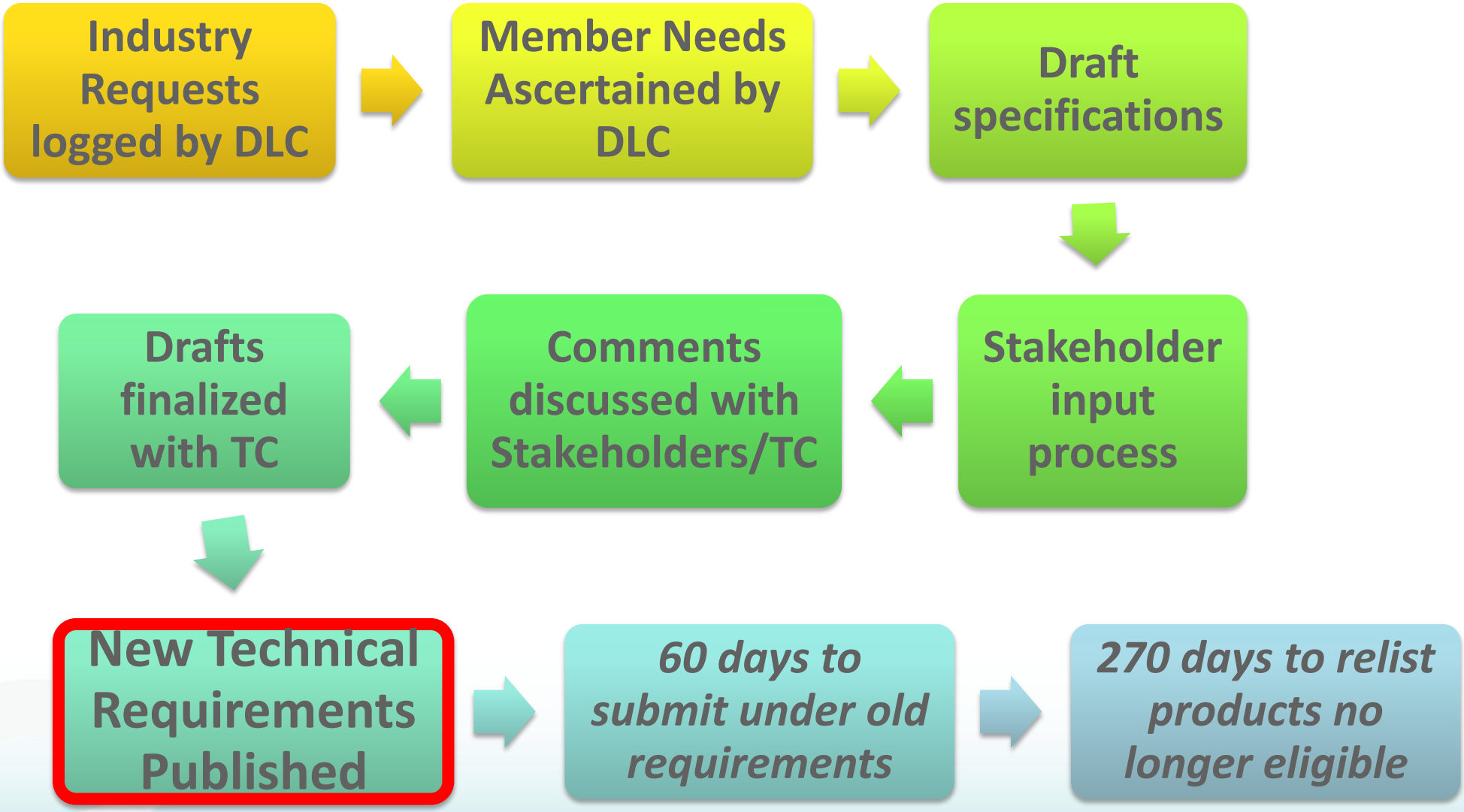
Warranty

5 years

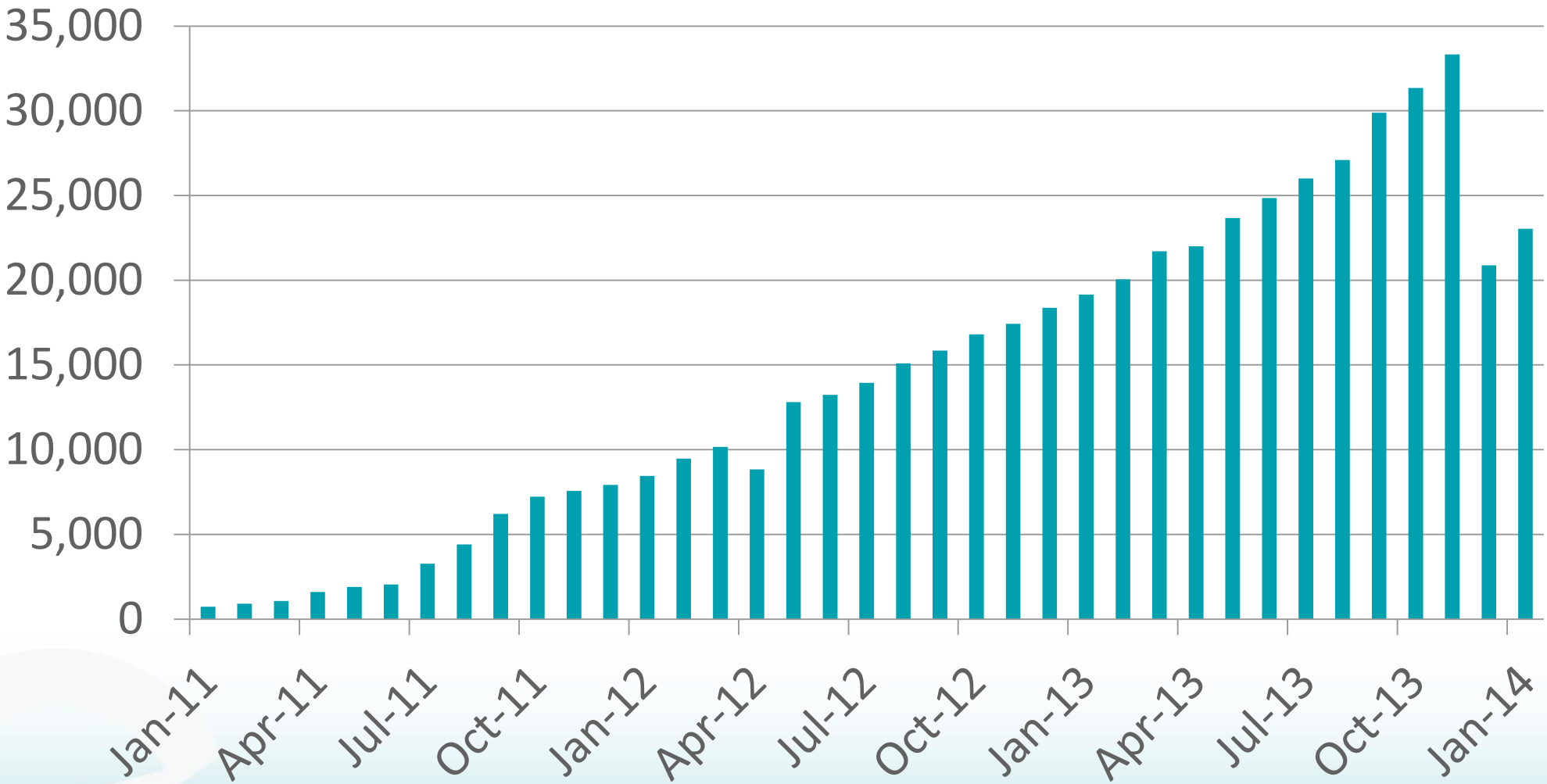
Category Development



Technical Requirements Evolution



Growth of QPL

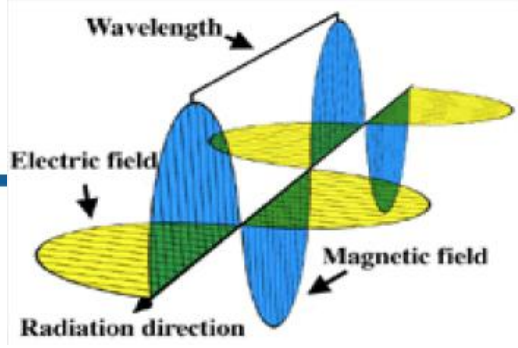


Light

Color

Color Quality

Light – What is it made of?



Light is made of waves

(technically: electromagnetic waves of radiant energy)

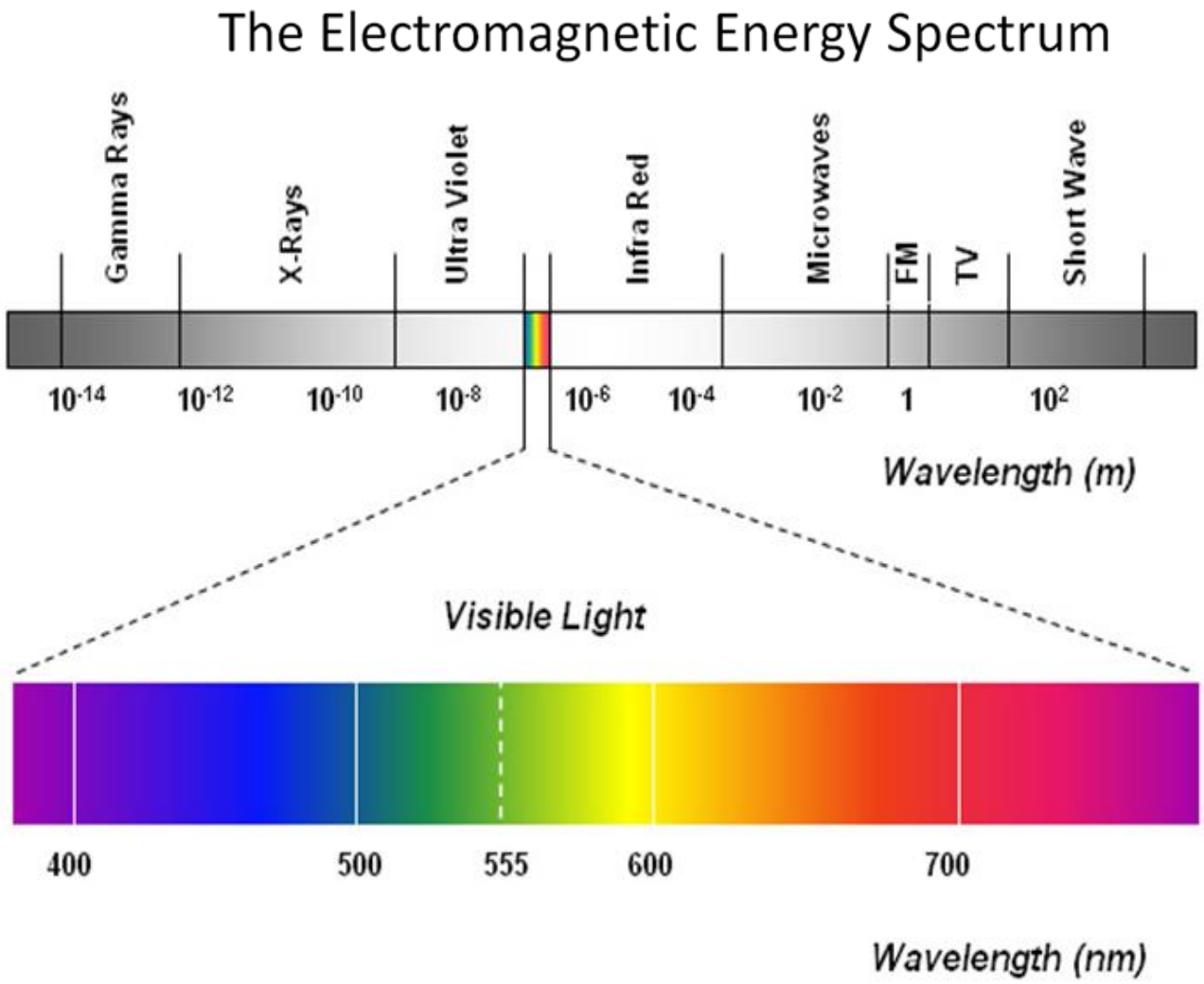
very small waves…

Lights wavelength is measured in billionths of a meter, nanometer (nm)

UV, Infrared (IR) heat, cell phone radio waves, X-rays are the same waves…

just longer or shorter

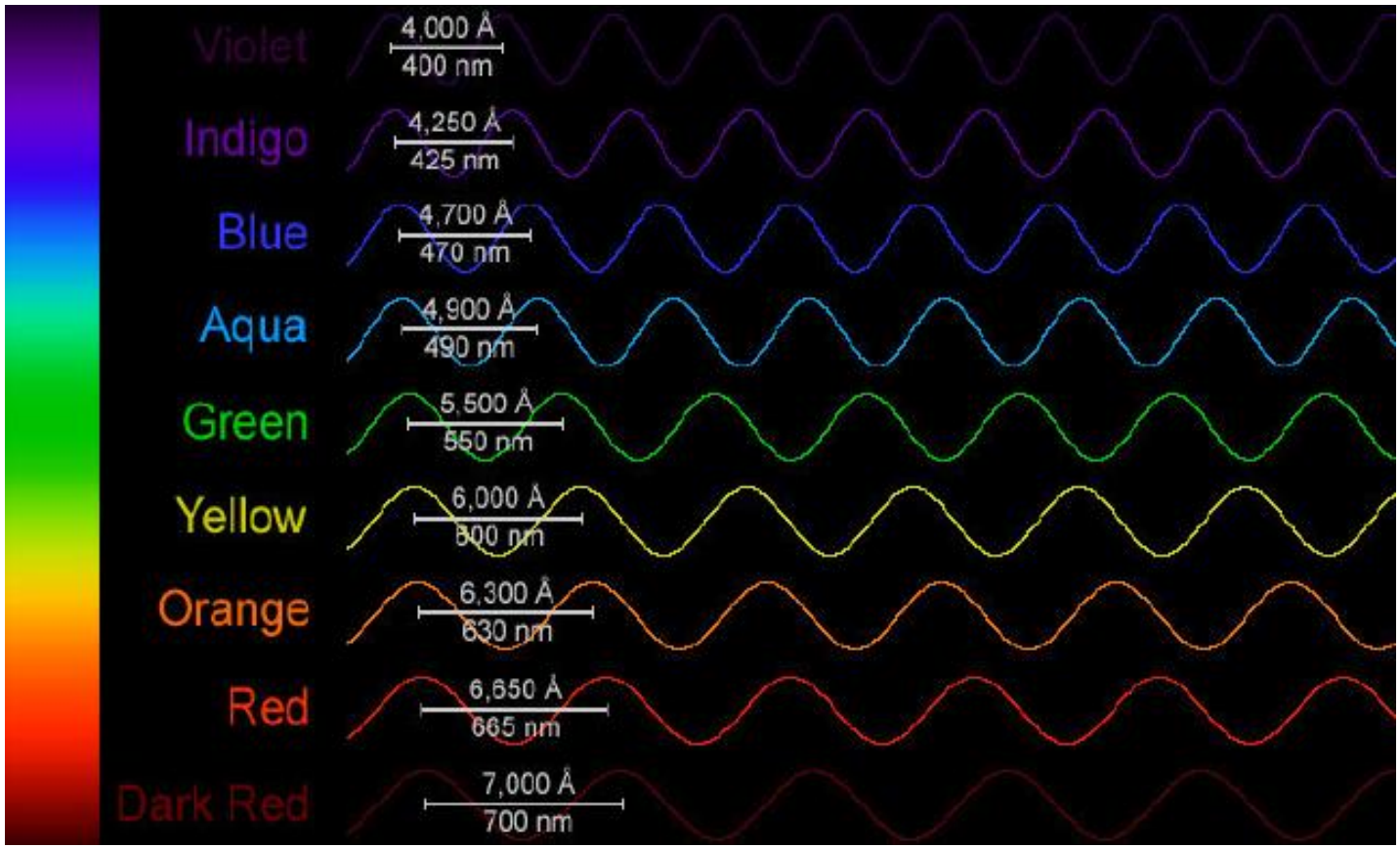
Visible Light is wavelengths between 380nm and 780nm



- # Different Wavelengths = Different Colors

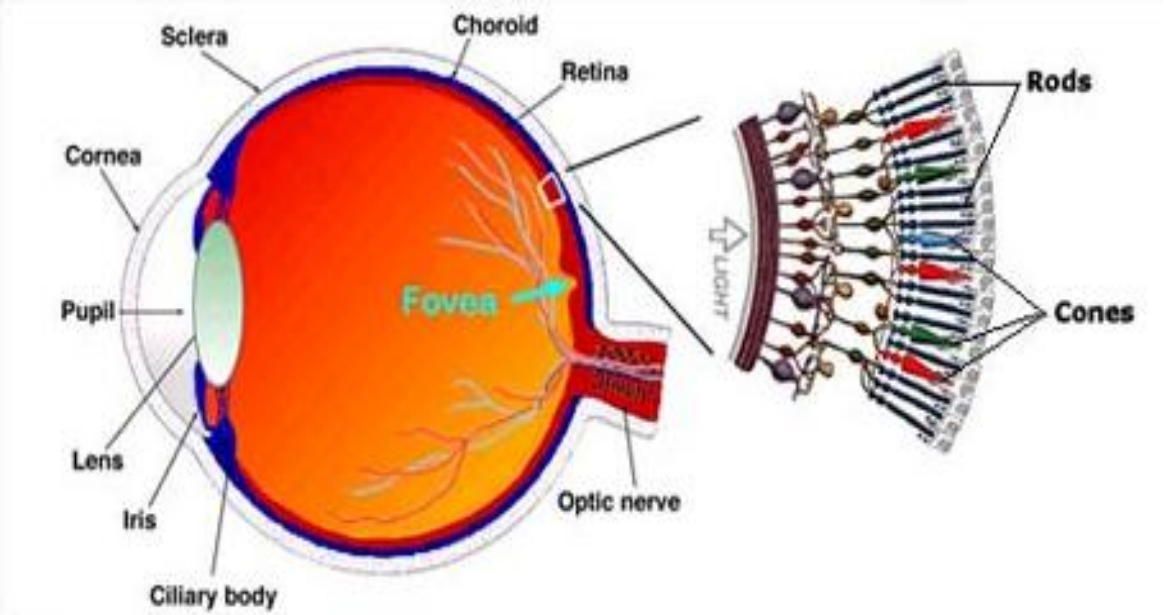
Light comes in different colors, spread across the rainbow of hues we call the visible spectrum.

Red waves are the longest, purple the shortest



Visible Light

How Do Humans “See” Color?



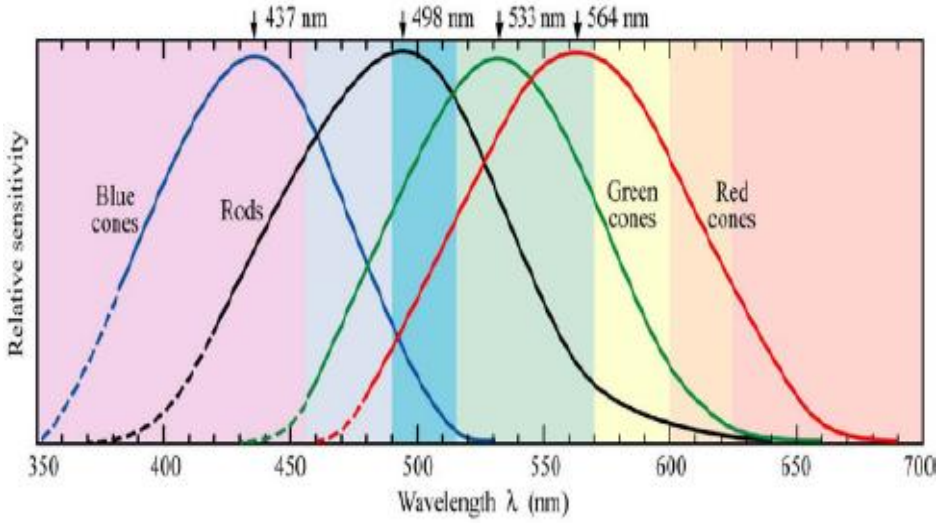
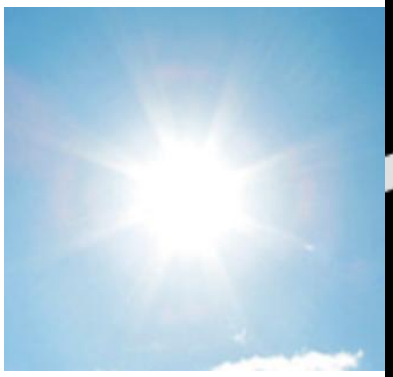
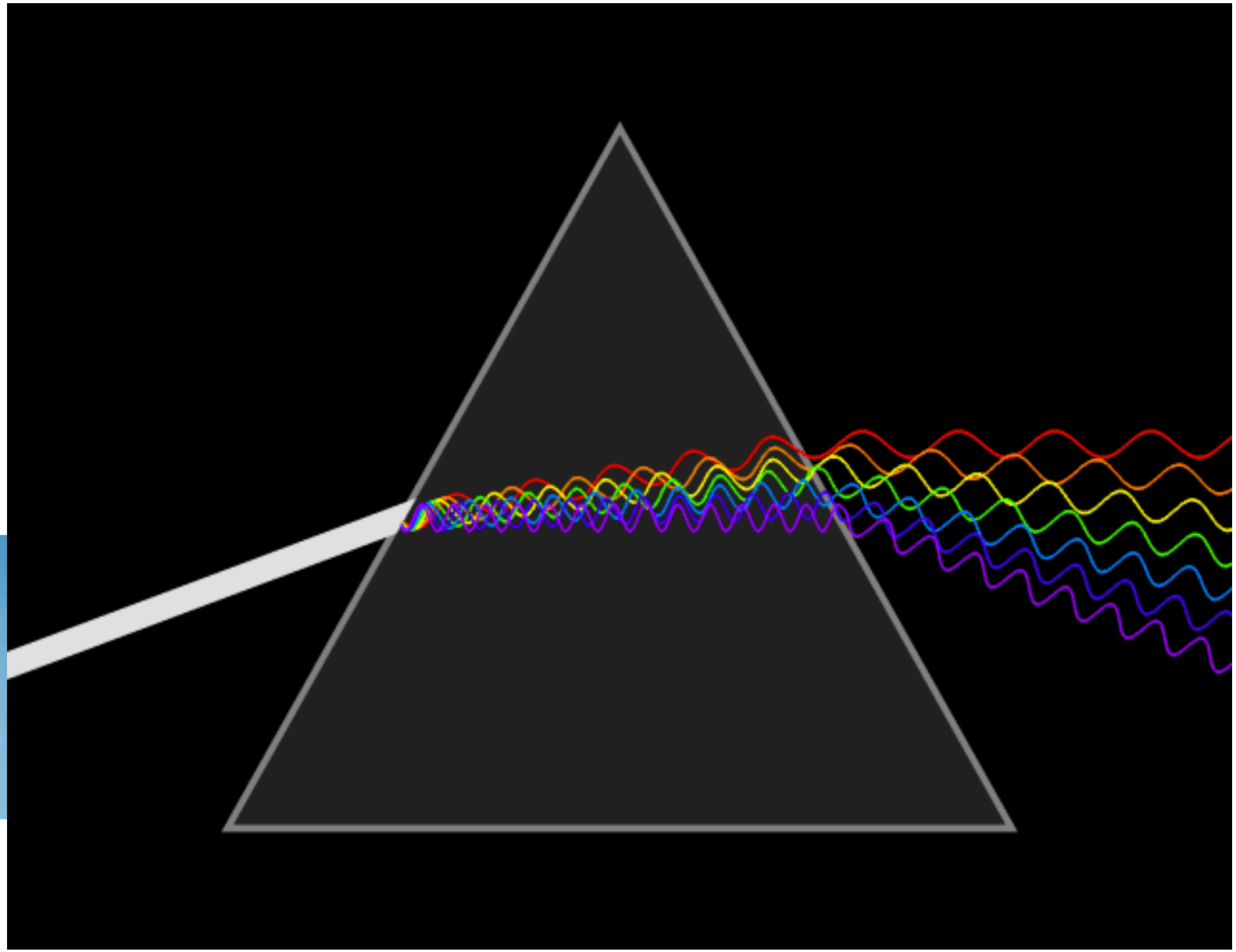


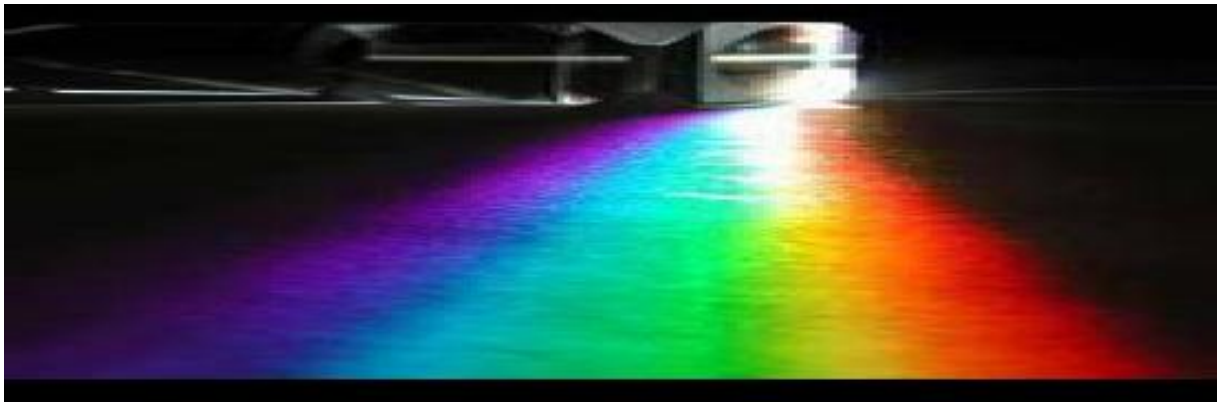
Fig. 11A.2. Normalized spectral sensitivity of retinal rod and cone cells of the human eye (adapted from Dowling, 1987).

- The eye contains cones and rods - cones are color sensitive and used for high light level vision (photopic) , rods are for night vision (scotopic)
- Three types of cones – long, medium and short .. Sensitive to red, green and blue areas of the visual spectrum
- Cones are concentrated in high density in fovea, Rods are spread across a much larger area inside the eye



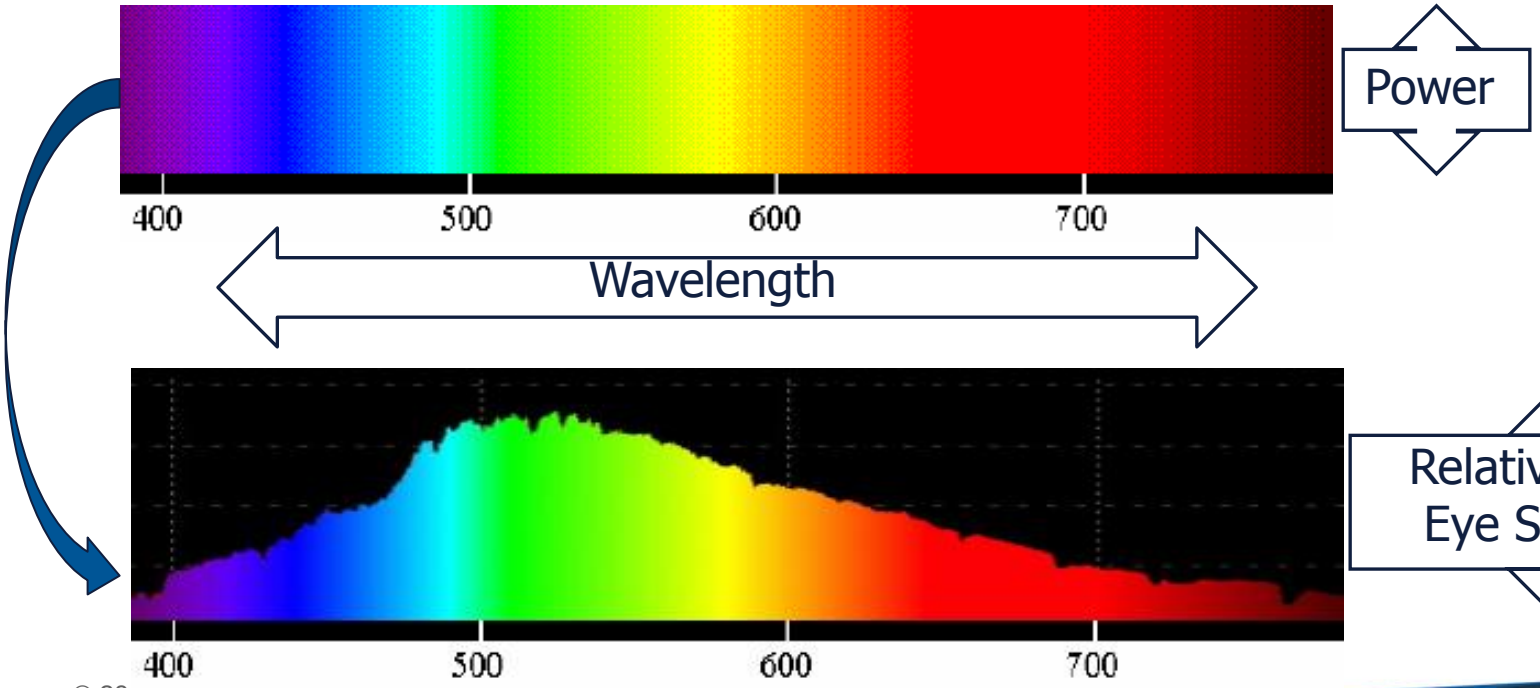


Color Intensity Perception

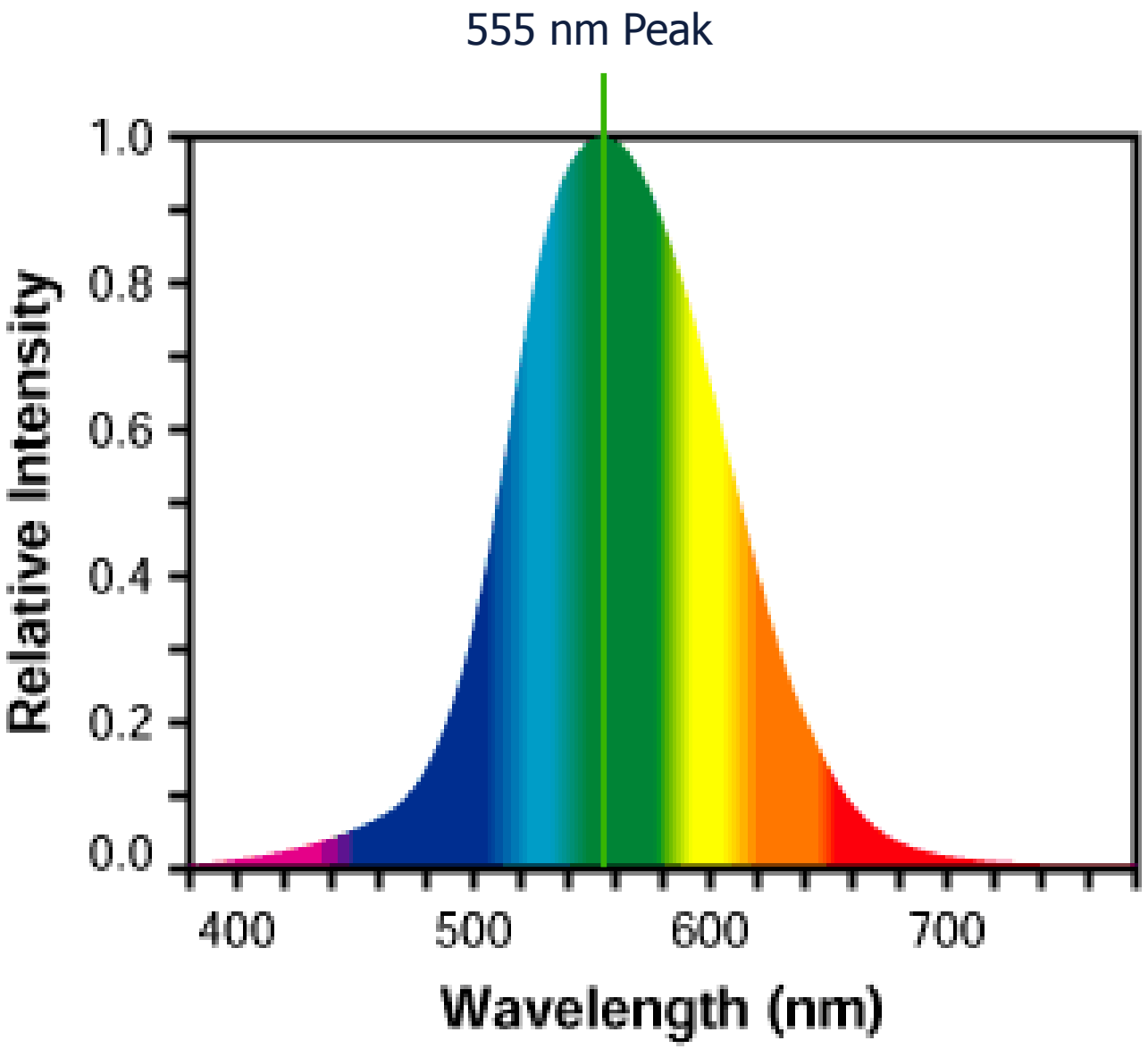


White light consists of many colors mixed together

Natural White Light (such as sunlight) consists of a continuous spectrum of all colors



The Human Eye Response Curve



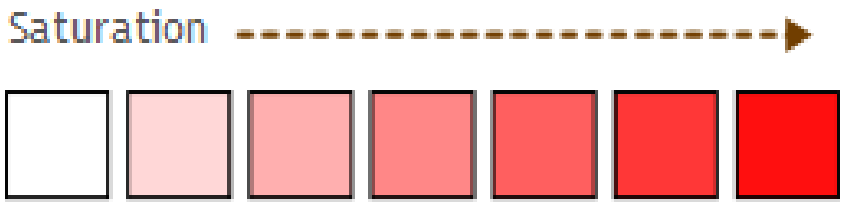
1931 CIE Chromaticity Diagram

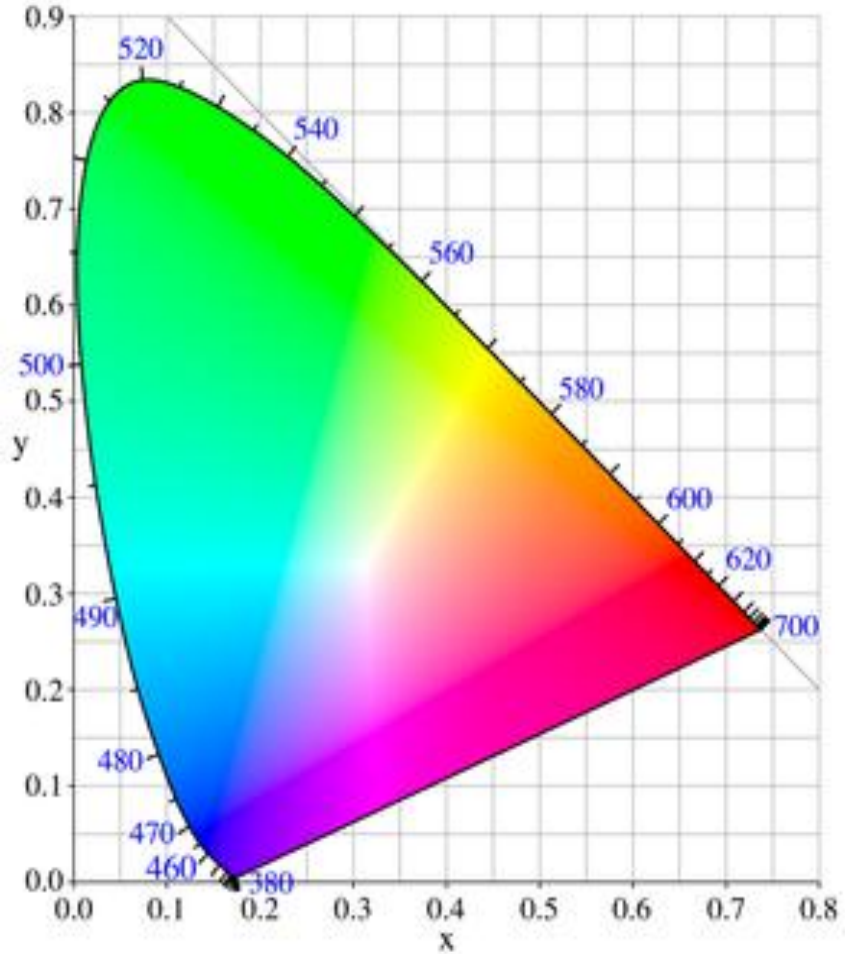
How It Works

- Monochromatic ("high Saturation") colors are on the outside edge of the diagram

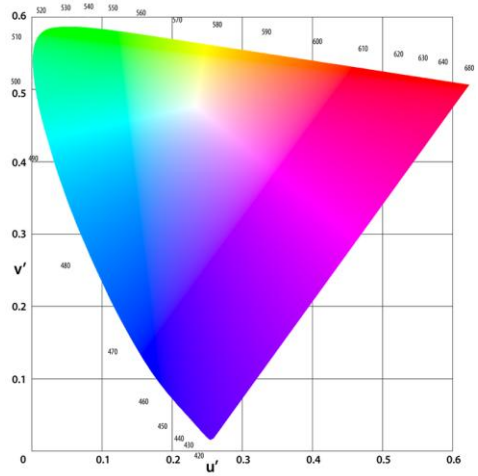
  "**The Spectral Locus**"

  - All combinations of colors are on the inside, with white colors in the middle

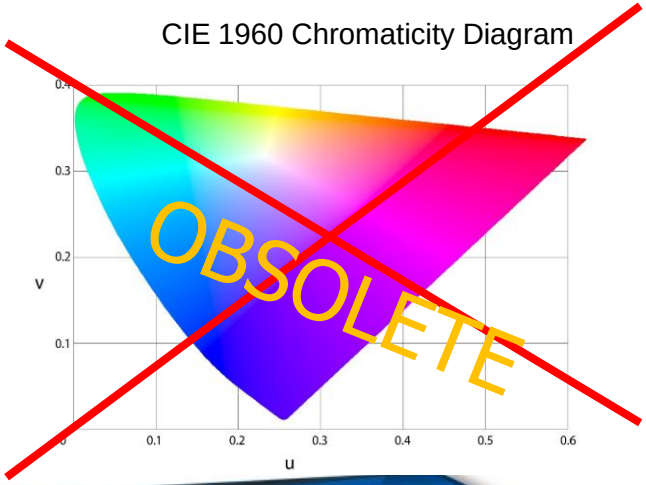




1976 CIE Chromaticity Diagram



CIE 1960 Chromaticity Diagram

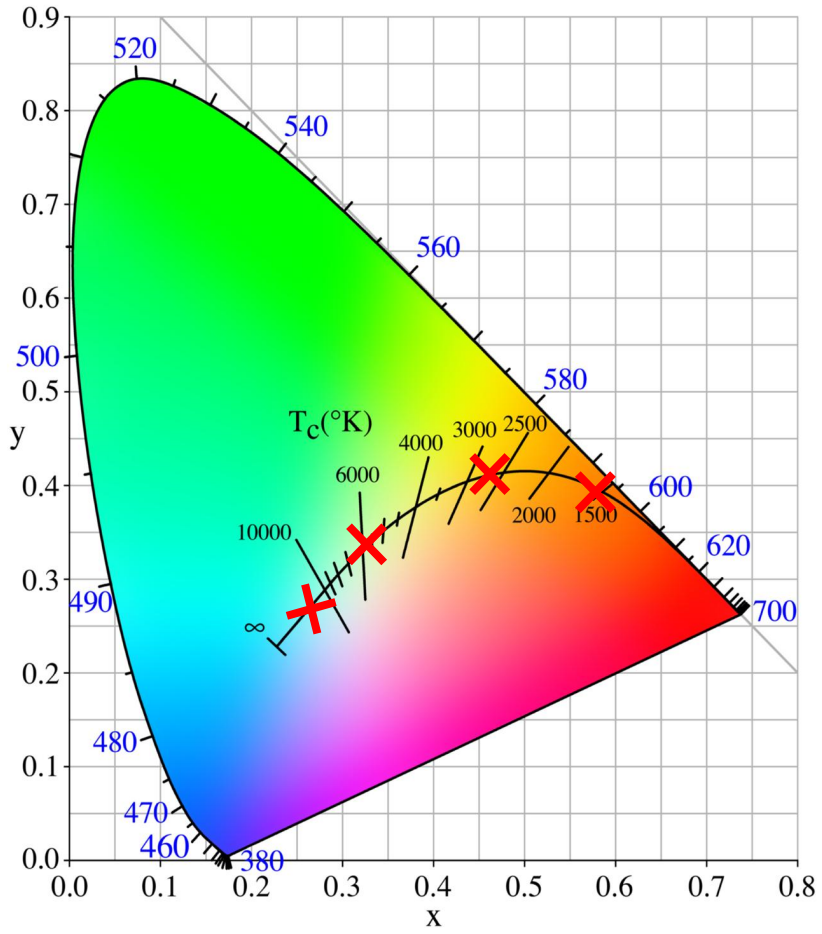


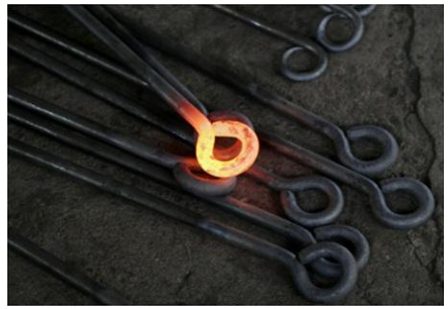
Blackbody Radiation

Noon time sun @ ~ 6000K
Cool White

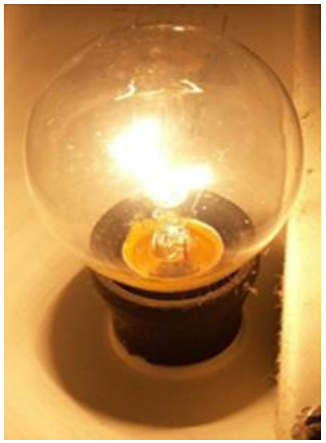
B type star >11,000K
Cool White

1931 CIE Chromaticity Diagram



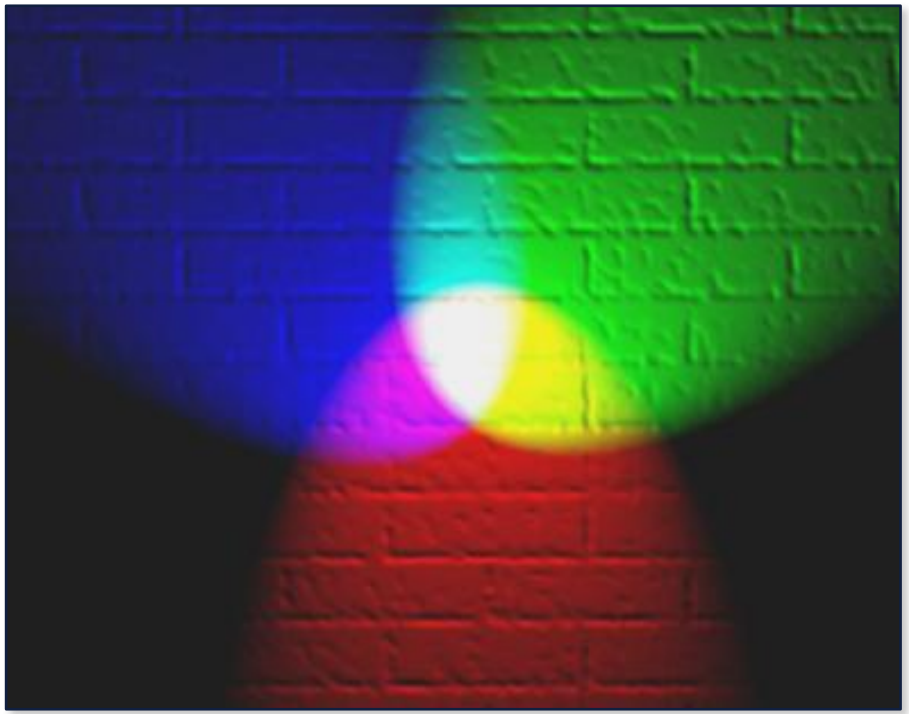


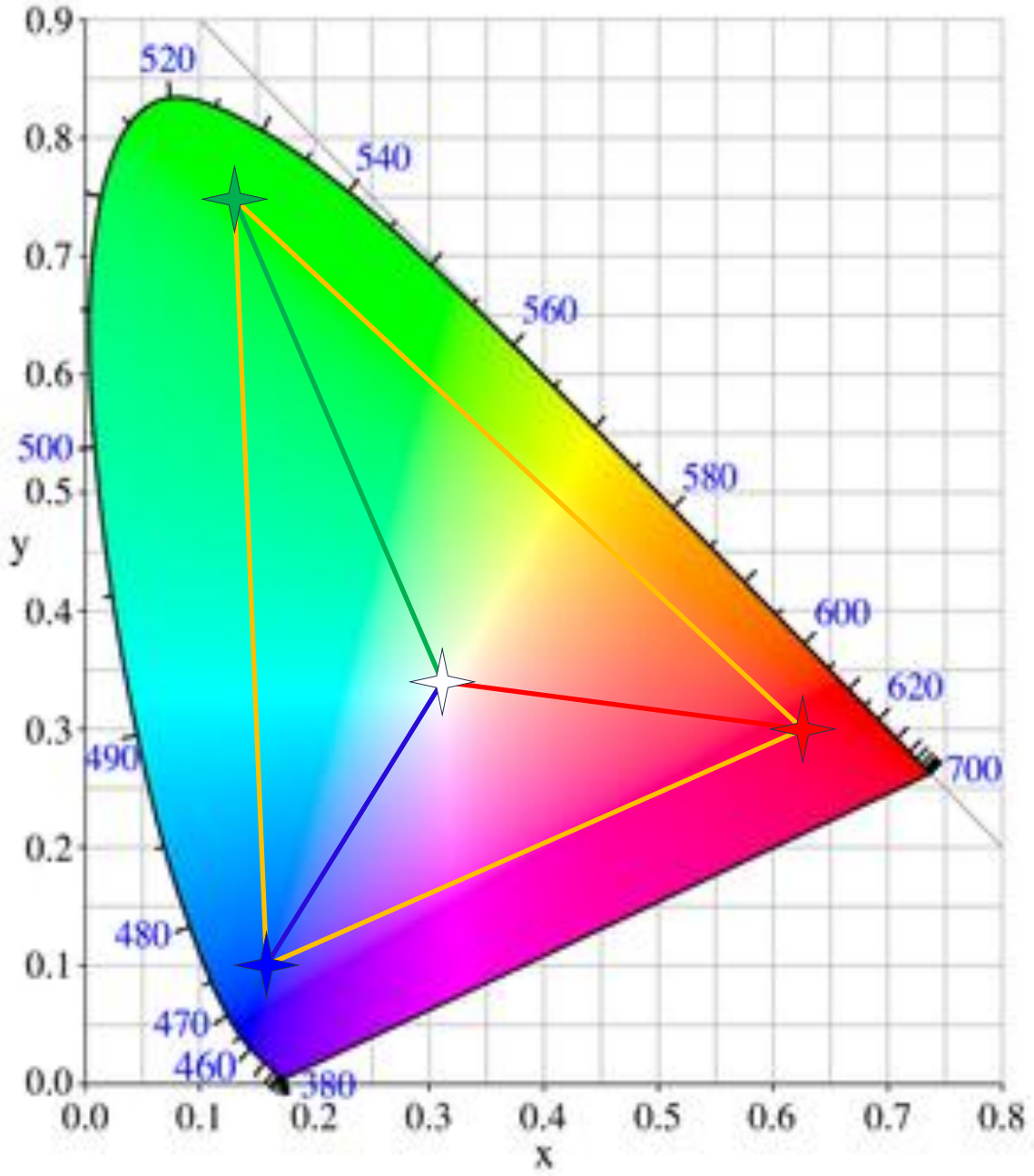
Steel @ 1500K
Warm White



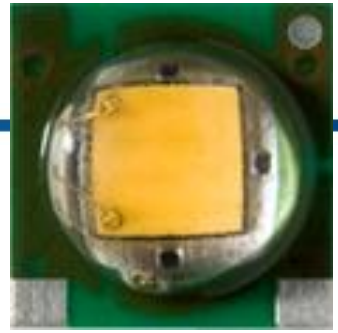
Tungsten @ 2700K
Warm White

Color Gamut

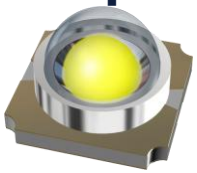


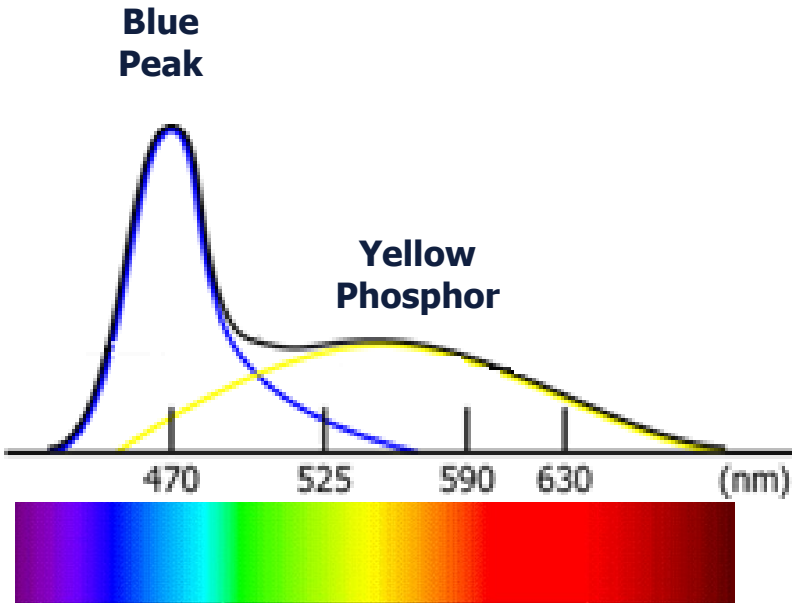


LED - Ways to White

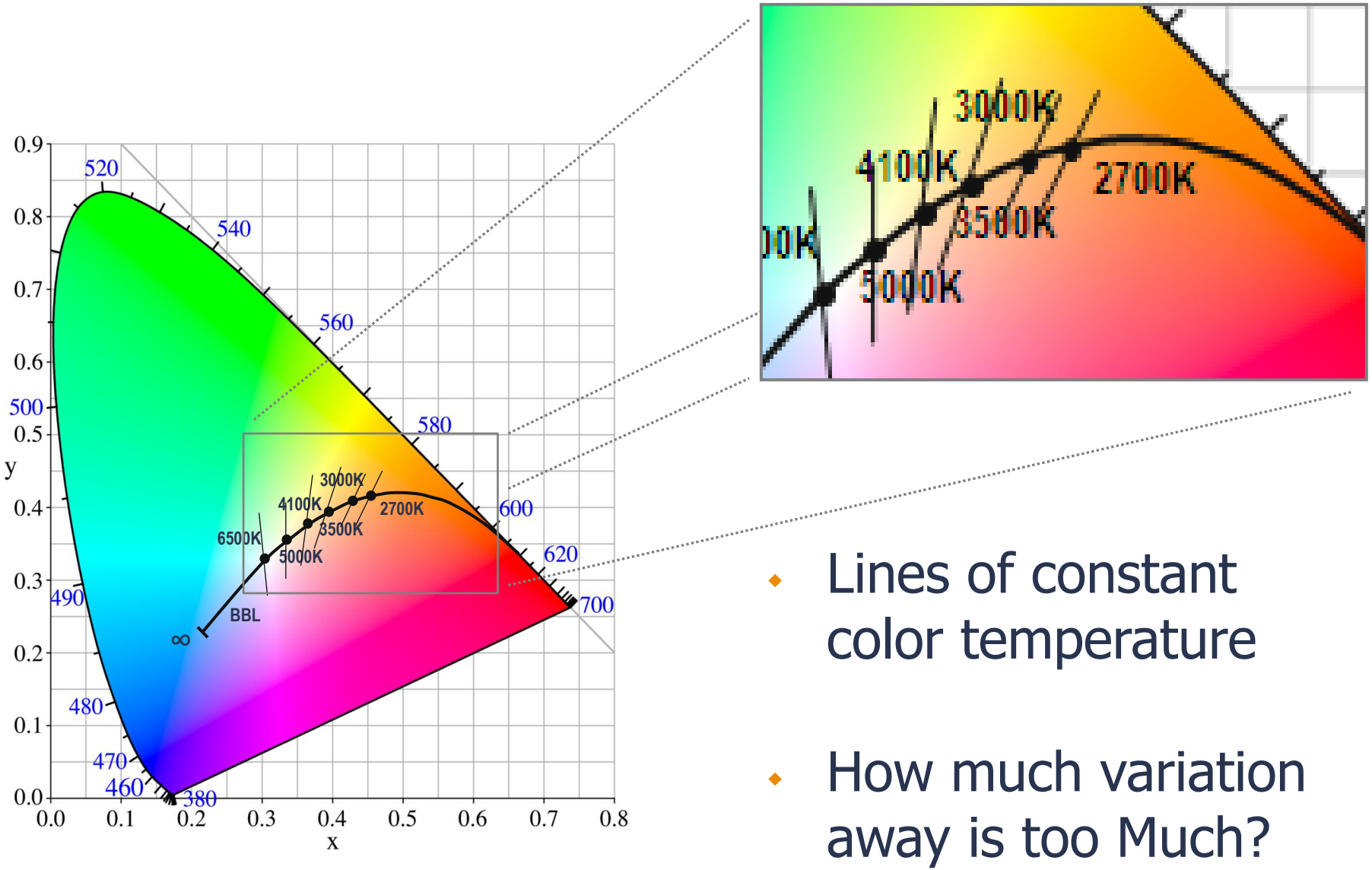


Blue + Yellow Phosphor



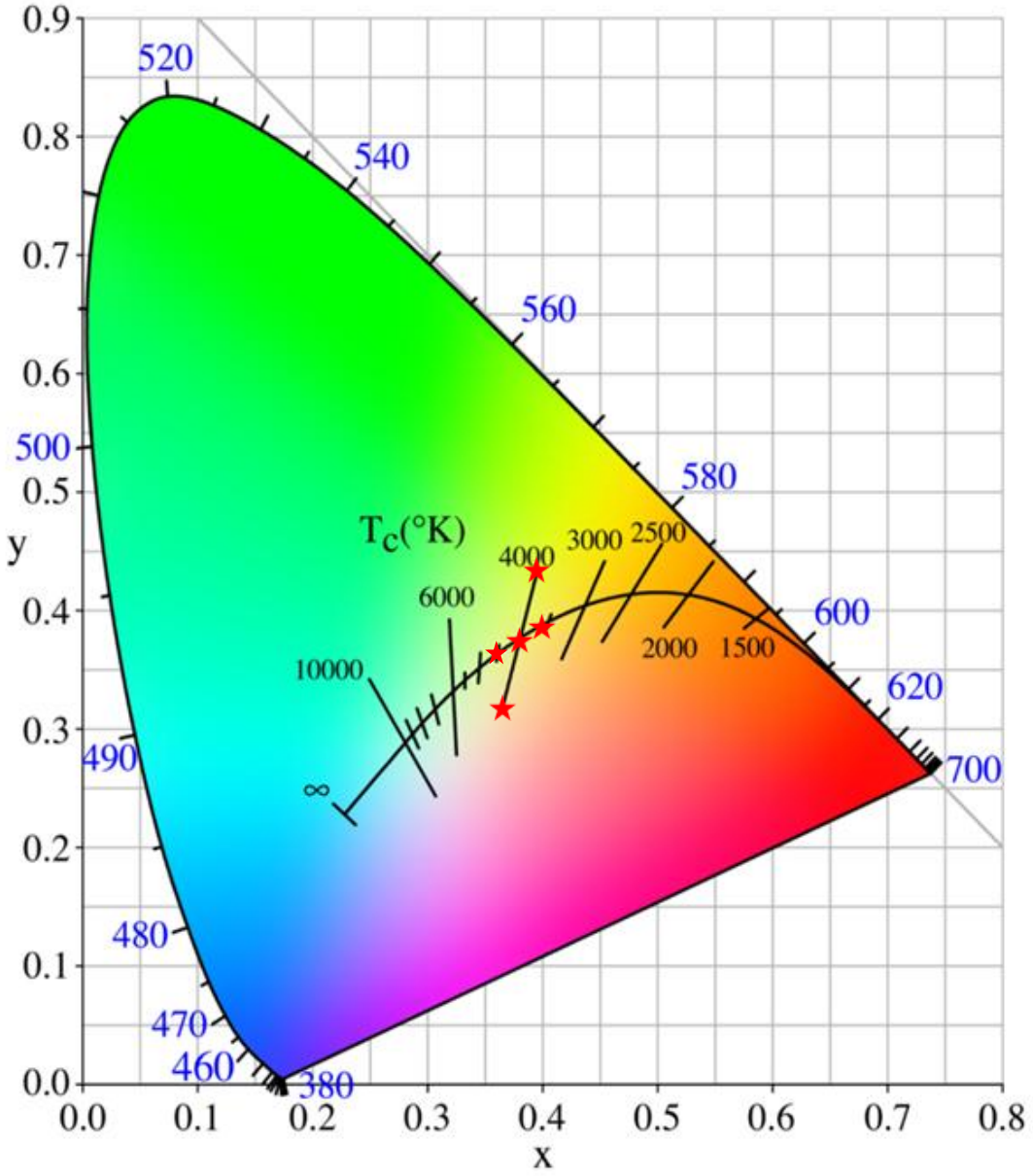


Correlated Color Temperature (CCT) Variation

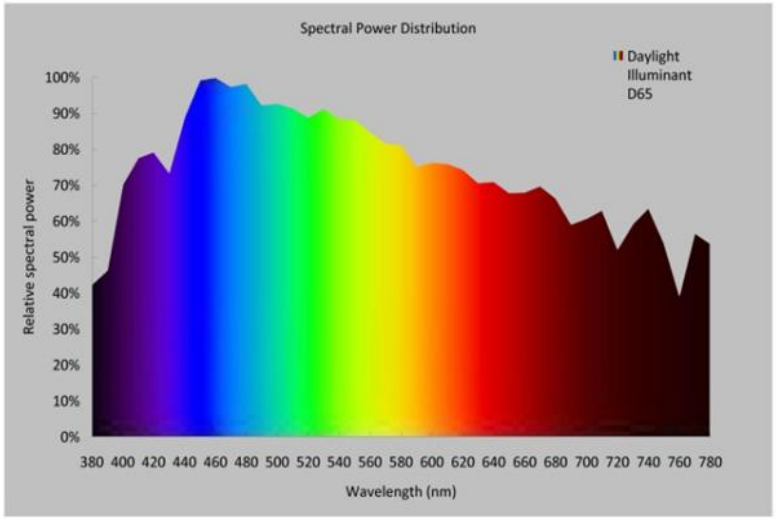


- Lines of constant color temperature
- How much variation away is too Much?

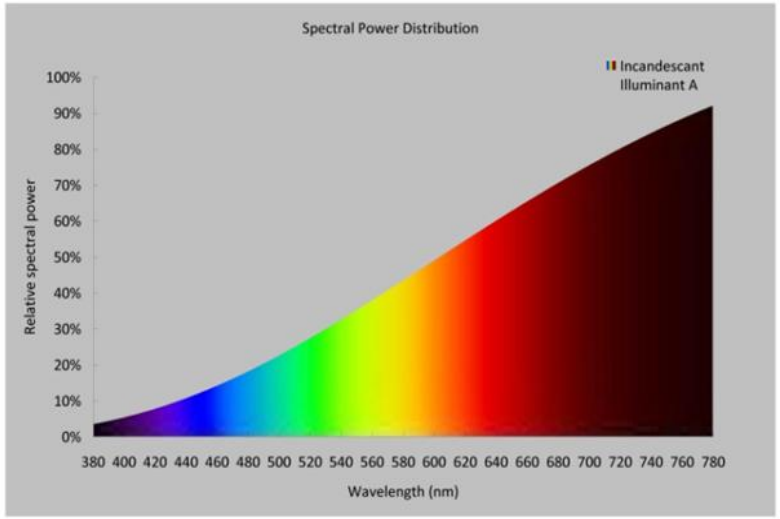
Color Variation



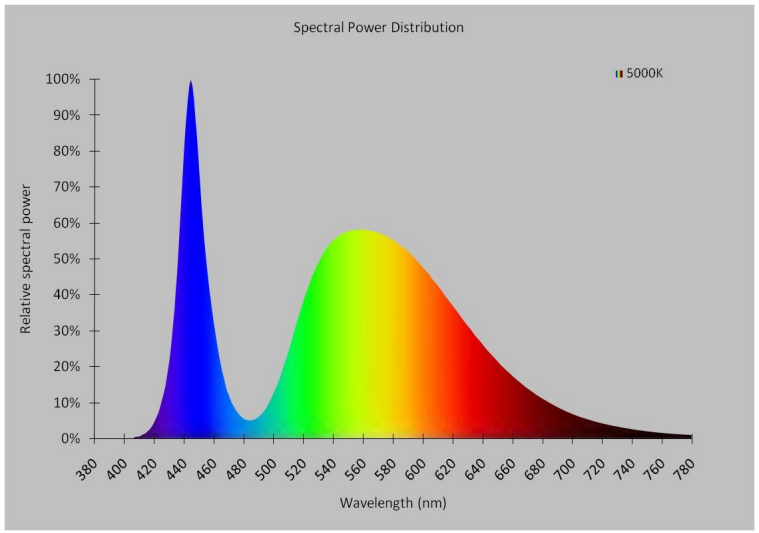
Spectral Power Distribution

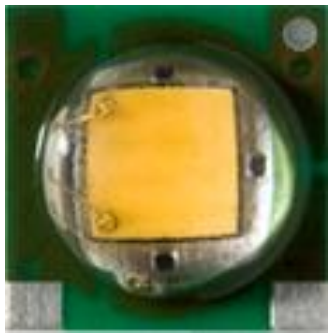


Daylight



Incandescent

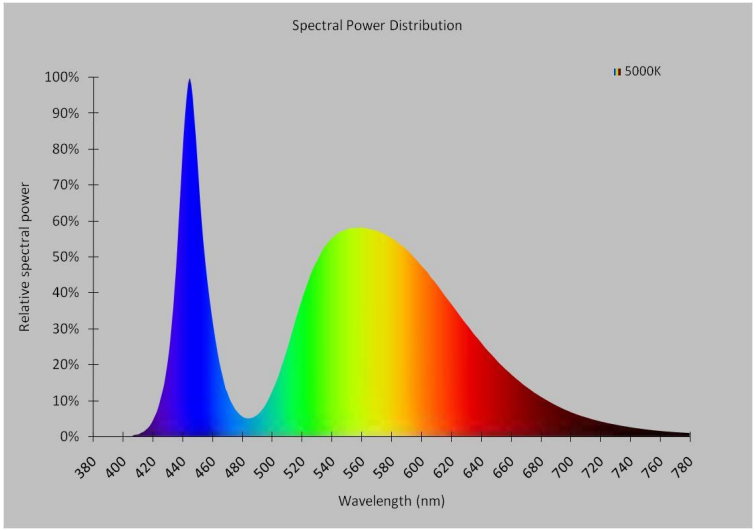


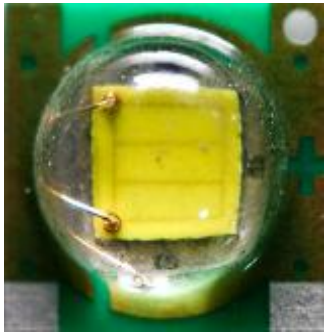


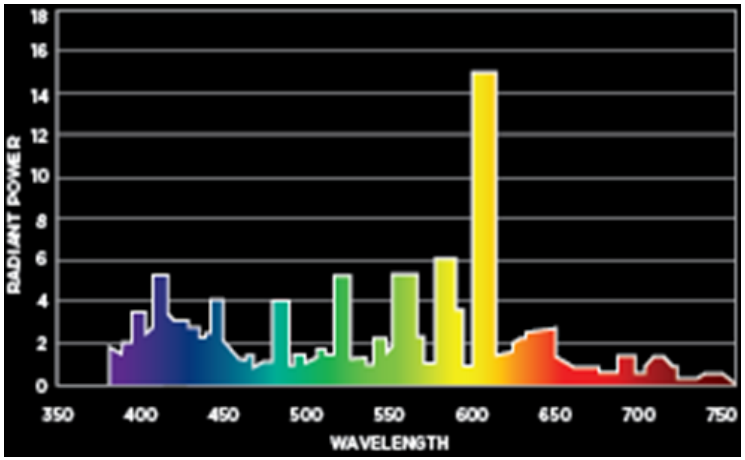
Phosphor Converted LEDs

Spectral Power Distribution

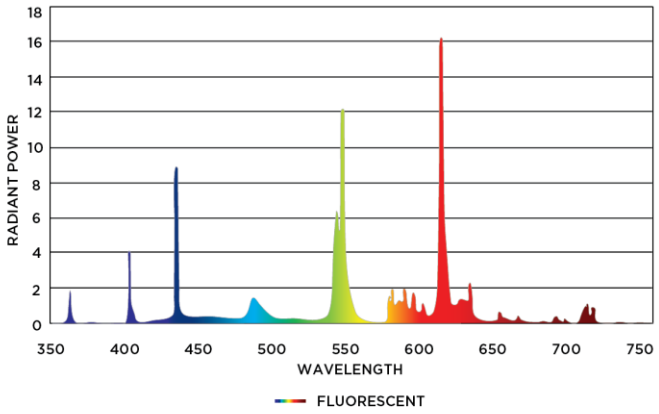
Phosphor Converted LEDs





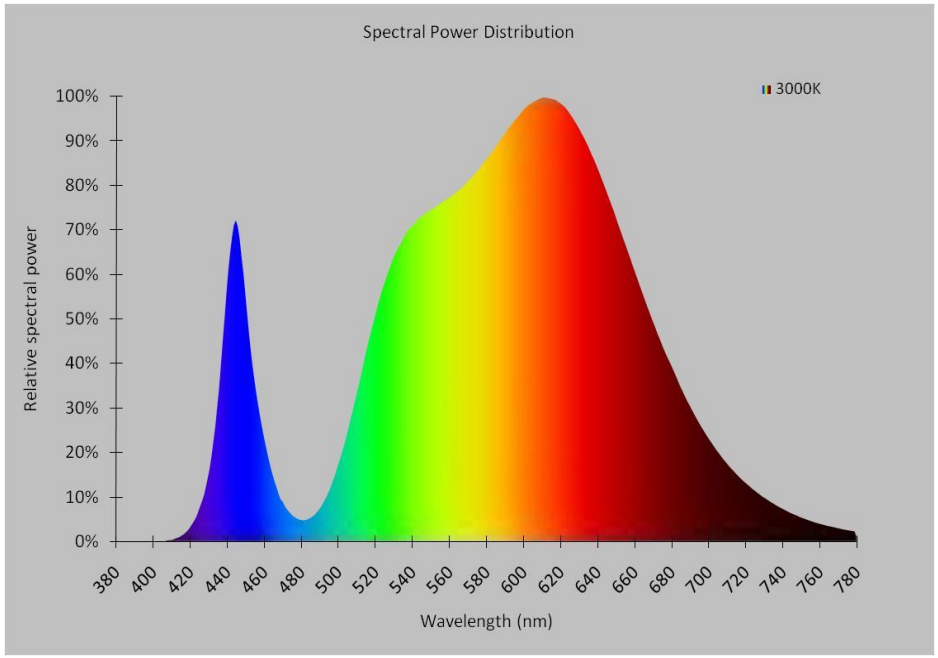


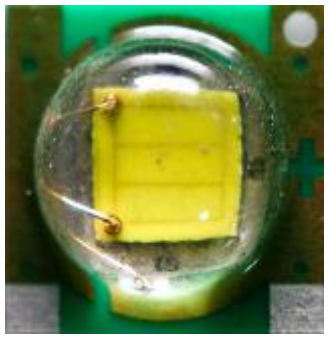
Metal Halide

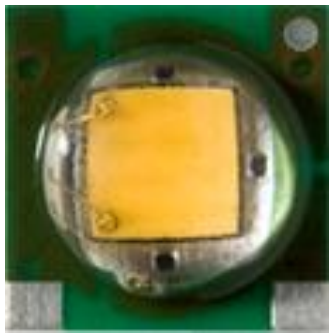


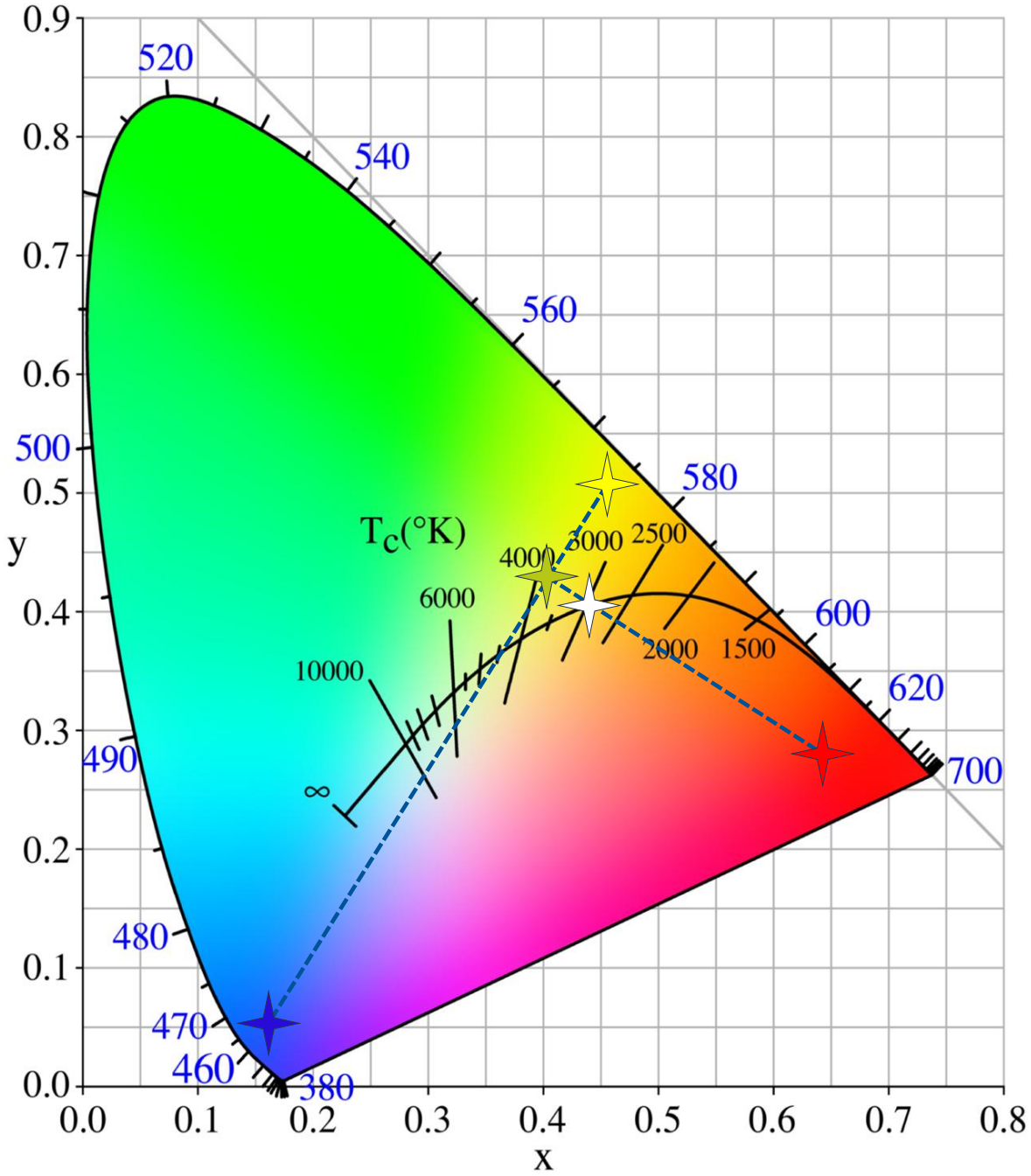
Fluorescent

Phosphor Converted LEDs









Color Rendering

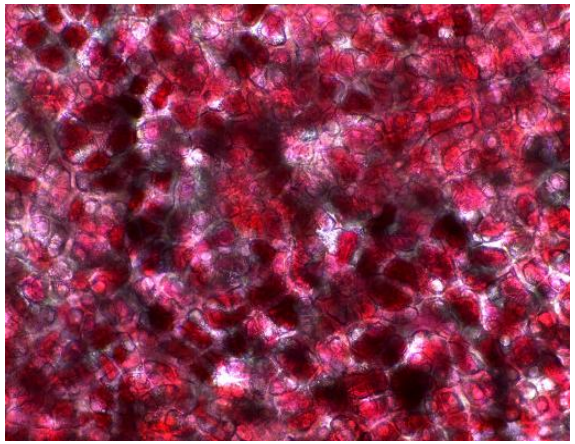
• Color Rendering Index (CRI)

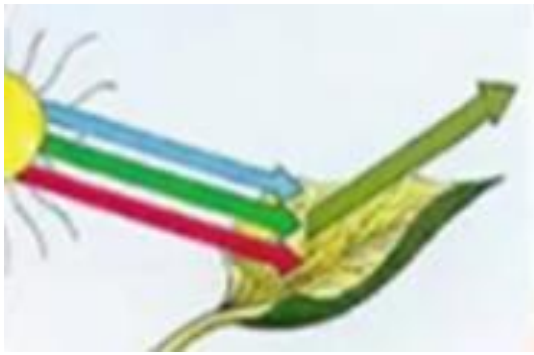
- A quantitative measure of the ability of a light source to reproduce the colors of various objects faithfully in comparison with an ideal or natural light source
- Ranges from 0 (poor) to 100 (excellent)

CRI = 62

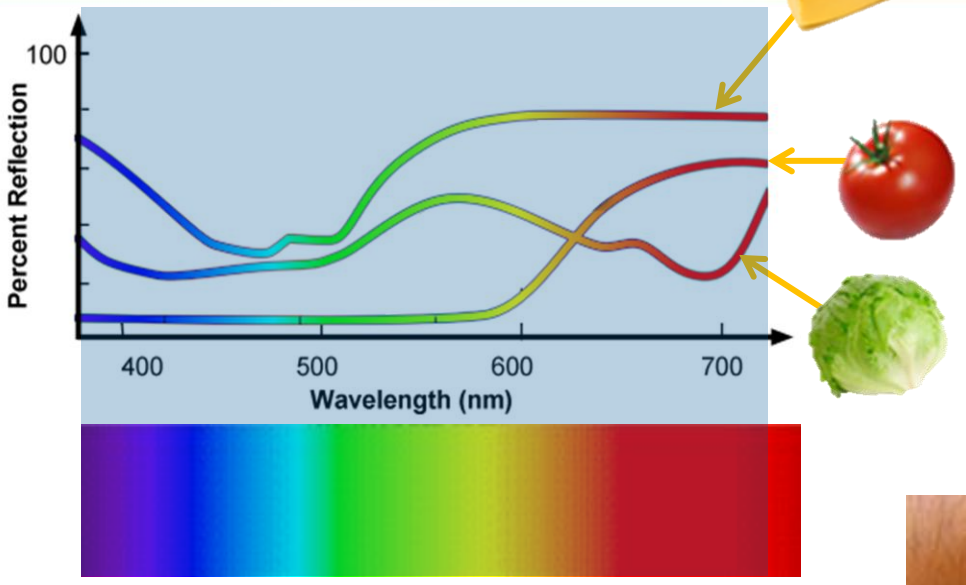
CRI = 93

Object Color





Object Color



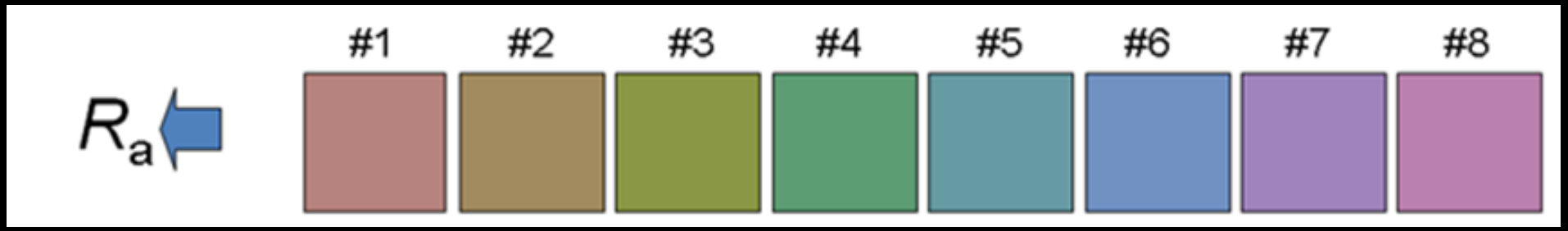
Spectrum

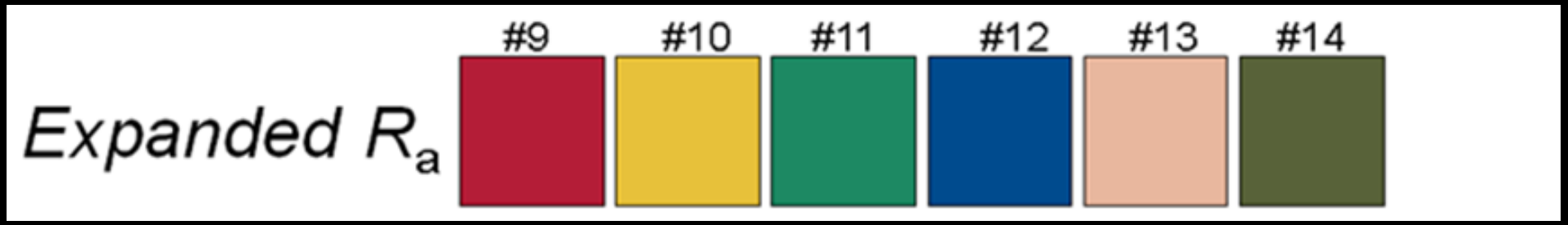
Object Color

Vision

Color Rendering Index

In general terms, CRI (R_a) is a measure of a light source's ability to show object colors "realistically" or "naturally" compared to a familiar reference source, either incandescent light or daylight.





None of the 8 test colors used to calculate CRI are saturated. So, CRI is a poor measure for indicating how well a light source illuminates saturated colors.

Even with a high CRI (R_a), color rendering of saturated colors can be poor.

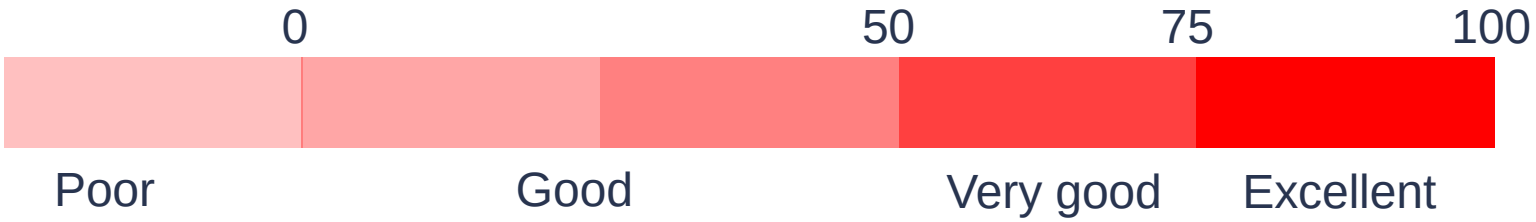
CRI With Expanded R_a Example

Color Rendering Index Detail								
R1	R2	R3	R4	R5	R6	R7	R8	Ra (CRI)
81.4	89.9	94.7	79.4	80.7	85.3	84.0	64.1	82.4

Color Rendering Index Detail (Expanded)								
R9	R10	R11	R12	R13	R14			
17.6	74.9	76.3	67.2	83.2	96.9			

Color Rendering Index – R9

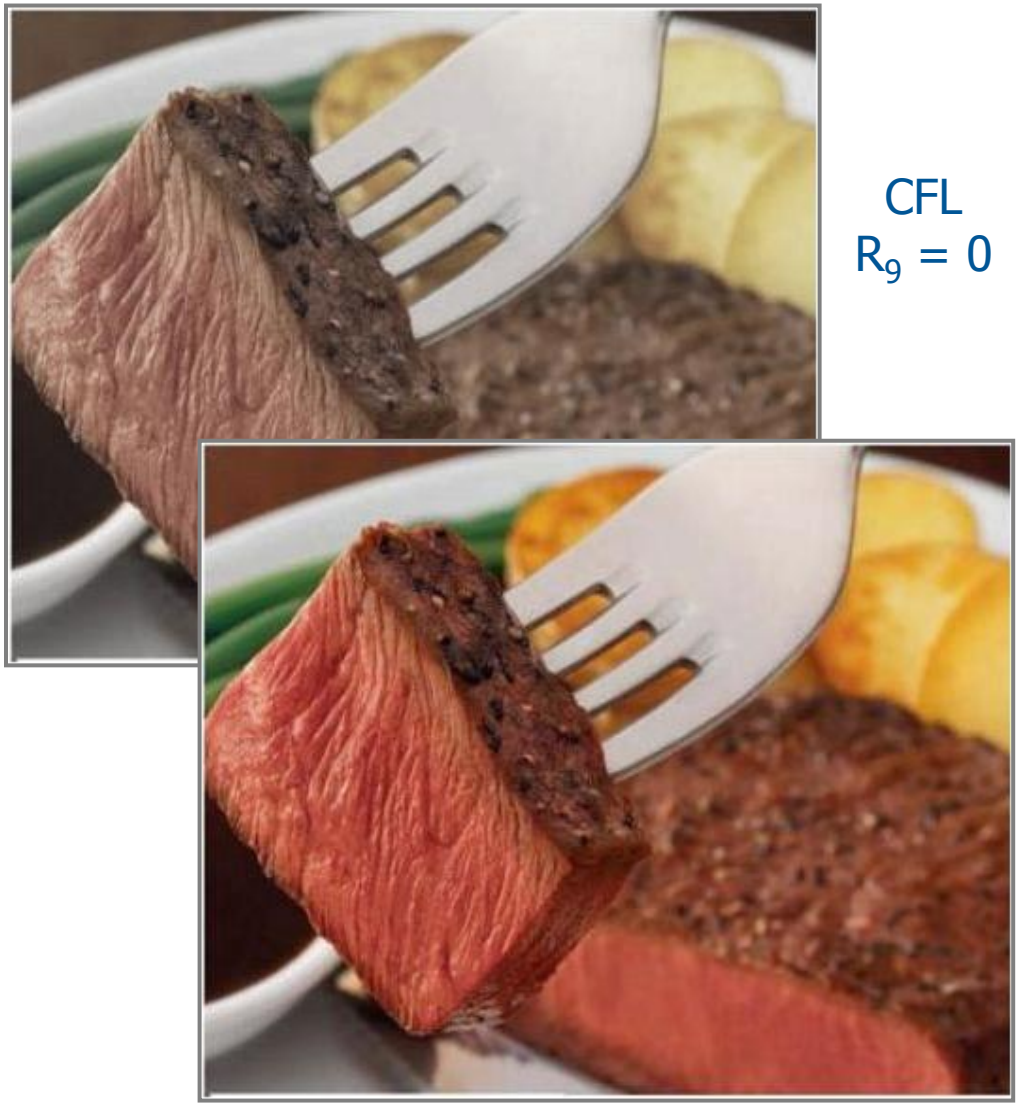
U.S. Department of Energy (DOE) Comments:



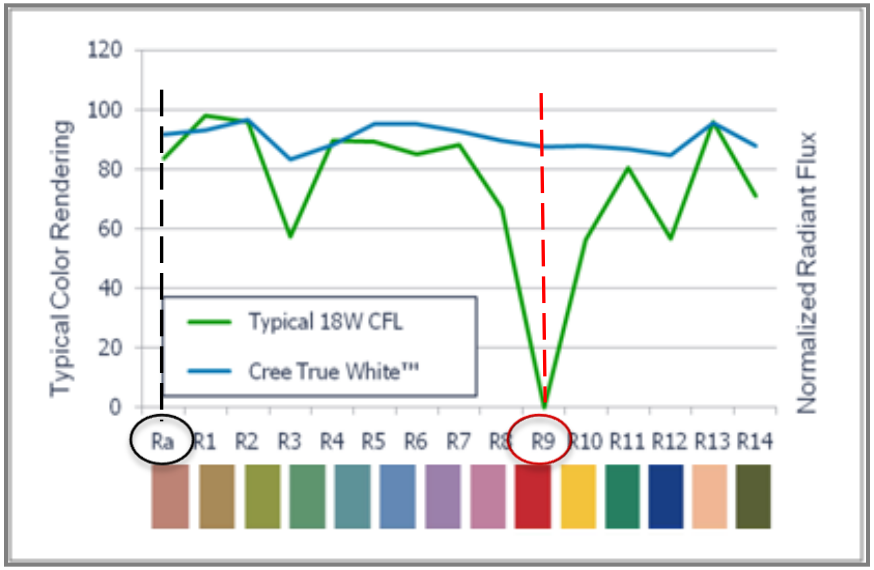
Special Color Rendering Index R_9

A measure of color fidelity that characterizes the similarity in color appearance of deep red objects under a given source relative to a reference source of the same CCT. The maximum possible value is 100, with higher scores indicating less difference in chromaticity for the color sample illuminated with the test and reference source. R_9 and R_a (CRI) are part of the same CIE Test-Color Method, but the R_9 color sample is not included in calculation of R_a. R_9 values should not be compared to R_a (CRI) values. As a shorthand approximation, an R_9 less than zero is poor, an R_9 greater than zero is good, an R_9 greater than 50 is very good, and an R_9 greater than 75 is excellent.

Why Your Customer Cares about #9



CFL
$R_9 = 0$



Cree TrueWhite ®
$R_9 = 90$

CRI of Some Common Sources

Light Source	CRI
60W Incandescent	100
Halogen	98-100
Cree TrueWhite™	90-93
Ceramic Metal Halide	85-90+
High CRI LED	88-90
Warm White LED	80-85
T8 Fluorescent	78-82
Cool White LED	65-75
Metal Halide	60-65
Mercury Vapor	<50
High Pressure Sodium	<25
Low Pressure Sodium	0-18

Rule of Thumb (US, EU):

THANKS!

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